THE PHYSICAL SCIENCE OF FLOUR MILLING

By

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LIVERPOOL :
Printed by THE NORTHERN PUBLISHING CO. LTD.,
28 PARADISE STREET.
1930

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Preface

to

"THE PHYSICAL SCIENCE OF FLOUR MILLING."

The existing books on flour milling fall into two classes. The classic book is Professor Kick's, which begins with a history of flour milling, gives some description of wheat and its impurities, then goes on to describe in detail various types of machines manufactured by different milling engineers, and finally discusses the flour milling diagram and the results that can be achieved, Many books have been published on similar lines in Germany, England and America. Broadly speaking, these books are descriptive and make little attempt to deal with the principles or science of flour milling.

There is a second class of book which deals with the chemistry of wheat and flour. Some of these are thorough and able scientific treatises; conspicuous among them are Kent-Jones's "Modern Cereal Chemistry," Jago's "Science and Art of Breadmaking" and Bailey's "The Chemistry of Wheat Flour."

But there seems to be no book in any country which attempts to deal with the principles of flour milling *engineering*, that is to say, with the *physical* science underlying the design of the machinery necessary to clean the wheat berry and to split it up into the desired products.

This book is an attempt to fill the gap. It has grown out of three papers read by me before the National Association of British and Irish Millers :

" An Analysis of the Power required to drive a Flour Mill," in 1913.

" The Principles of Wheat Conditioning," in 1923.

" Flour Milling Research," in 1928.

These papers, as well as the present book, are based on the experience of flour milling and flour milling engineering gained by the staff of Henry Simon Limited, during the past fifty years. Although I am personally responsible for the matter contained in this book, it could never have been written without the full and ungrudging help of many of the practical and scientific members of the staff. The greater part of the research work on which many of the chapters of the book are based has been carried out by Mr. G. Watts, who is also mainly responsible for the chapters on air separation, dust collection and purification. Mr. C. Raeburn has given general editorial assistance, and is almost wholly responsible for the chapter on separation by size, and for the greater part of the work in the two chapters on conditioning. Further, I am indebted to Mr. R. J. Fowler, and many of the members of our expert milling staff, for the valuable help and advice they have given in regard to the technical milling facts. The late Mr. A. D. Johnston carried out all the experiments for the chapter on power. Mr. C. W. Chitty and Dr. D. W. Kent-Jones were kind enough to read the book in manuscript and to make a number of valuable suggestions.

Table III., Chapter VIII., Page 137, which shows the amount of bran powder produced by the

different machines in the mill, is probably the most interesting and novel feature of the book. I believe the method adopted, of testing the work of the mill by measuring the production of bran powder at different points, is novel, and is a method which, if properly developed, would go some distance towards providing a sound basis for a real science of flour milling. Not only does it give a new possibility of measuring and recording numerically such improvements as are made, but even in its present form it is pregnant with suggestion as to the parts of the diagram where the damage is done and, therefore, as to the lines which future development must follow.

It is probably true to say that most milling machines have hitherto been designed, and are still being designed to-day, on a purely empirical basis, with little direct consideration or even understanding of the physical laws which control their working. It is undoubtedly true that on this empirical basis astonishingly good results have been obtained. There is, however, as will be shown later, plenty of room for further development, and I hope that this book may be of practical value in helping students of milling, designers of milling machinery, and managers in actual charge of the working of mills, to understand more clearly the scientific basis of their work.

Some of our staff doubt the wisdom of publishing fully and freely such scientific knowledge as is possessed by our firm, on the ground that it will help competitors and increase the pressure of competition—which is already quite keen enough! The Directors decided to over-ride this objection on the grounds, firstly, that such a publication is in the general interest, and secondly, that even from a purely selfish point of view, its publication would bring us into closer contact

with some of the ablest and most scientific millers all over the world. The result will, we hope, be that we shall learn so much from them as to outweigh any objections to the publication of our knowledge.

The knowledge of the principles underlying milling engineering is admittedly very incomplete to-day. The present book therefore can only be an attempt to deal with some of the principal aspects. It refers only very slightly to the whole question of the grinding of wheat, and does not deal at all with the problem of the best method of sifting the mill products. I believe, however, that it does contain a good deal of new information on the majority of the main problems of milling on the physical and engineering side, and I have decided to publish it without waiting to attempt to make it complete. I hope that as time goes on it may be possible to supply some of the main omissions and publish further editions on a larger scale. I should be very grateful to anybody, whether millers or milling engineers, who could send me any criticisms or suggestions to help to improve future editions.

E.D.S.

November, 1930.

Chapter I.

Introduction.

THE FIELD FOR DEVELOPMENT.

The practical object to be gained by studying the principles of flour milling engineering is to enable engineers to provide machinery which will carry out more efficiently or more cheaply the work of a flour mill. It is, therefore, important to ask whether, and to what extent, such development is required. Is the flour mill to-day efficient and economical? Does it do its job as well and as cheaply as possible, or is there room for improvement?

In attempting to answer these questions, it may be useful to glance at the developments which have taken place in the art of flour milling in the past. We use the word "art" deliberately, because the developments hitherto have been mainly on an empirical basis and a science of flour milling can hardly be said to exist.

The great revolution in flour milling was the introduction of the roller mill and the automatic gradual reduction system, roughly in the decade from 1880 to 1890. Modern milling may be said to date from that time; the flour obtained from a present day mill is so much better than that obtained from the old stone mill that comparison of the two types of milling is scarcely possible.

In order to form an idea as to the degree of efficiency to which the milling process has attained and the possibilities of further improvement, we propose to attempt to estimate the cash value to the miller in the United Kingdom of the improvements that have been made since the

introduction of automatic roller milling, and also the cash value of the further improvements that might theoretically be made. All these calculations will be based on the English sack of flour weighing 280 pounds.

The present roller milling system has been in force in this country for just under half a century. What technical progress has been made during that period ? There have been three main developments. The first is the introduction of washing and conditioning and of scientific control of moisture content of the wheat and its products at various stages of manufacture. In this country washing and conditioning are now practically universal. In countries like Australia and the United States, where the miller has to deal with clean wheats, the majority of mills are still without washers. The value of the washing plant is seen mainly in the improvement of the break flour, which may be 6d. a sack with clean wheats and up to, say, 3/- a sack on Indians. We have consulted some of the most experienced millers of the country, and the general consensus of opinion is that the actual net value to the British miller of a good washing and conditioning plant, after allowing for capital charges and the cost of operating, may be put at something like 6d. a sack of flour produced.

The second important change as against the early roller mill plants has been the elaboration and perfection of the diagram. The most important point which we have learnt from experience has been the importance of a long roller surface ; in addition to this, classification and purification of the stocks have been substantially improved. On the average it is estimated by experienced millers that the best plants to-day are about 1/- a sack net ahead of the best plants

of the first decade of roller milling in the value of the products from a given wheat mixture.

The third improvement has been in the use of chemicals for bleaching and strengthening the flour. These have been gradually perfected during the last twenty years and are now in very general use. The value to the miller of the skilful use of improvers and bleachers would seem to be about 1/- a sack.

Summarising these three improvements, we find that a modern plant to-day, with all the latest improvements, is about 2/6 a sack ahead of a plant erected forty or fifty years ago, the value of the products having been increased by something like 6%. In order to secure this advantage the plant has become considerably more elaborate ; washing and conditioning plants have been included, and the number of roller mills, and, to some extent, of other machines has been increased. A modern mill is, therefore, definitely more elaborate than the best plant was in 1890. The labour probably is about the same to-day as it was at that date. There is, thus, a slight increase in the capital cost and therefore in the cost of manufacture to set against the increased value of the products.

There has been no revolutionary change. Looking back over the history of the last fifty years, the progress in flour milling has probably been less than in the majority of industries ; even so, an increase in the value of the product of 2/6 a sack means something over four million pounds a year for the United Kingdom.

What are the prospects of either cheapening the process or improving the product in the future ? Can we hope for another 2/6 a sack, or is there an even greater field available ?

The first point we have to settle is what is the

aim of flour milling. This has been defined from the financial point of view in Pamphlet No. 2 of the excellent technical educational series published by the National Joint Industrial Council of the Flour Milling Industry, which states that " the amount added by milling to the value of the raw material is the measure of the merit of the work involved." That is the correct definition of the *merit* of the work ; to arrive at the *profitableness* of the work it is, of course, necessary to deduct the cost ; in fact the definition amounts to this, that the merit of the work involved is measured by the profit shown in the balance sheet at the end of the year, and that the best milling system is the one that results in the largest profit.

This will be universally admitted, but from the point of view of research it is necessary to have a more technical definition of what the miller is aiming at. This object may be defined as follows—

1. The removal of all impurities from the wheat, leaving it perfectly clean.
2. A perfect separation of the bran from the endosperm.
3. The production, from any wheat, of flour of perfect baking qualities, to suit the requirements of any system of baking.

It is, of course, a condition of efficiency that all these operations should be performed at the lowest possible cost.

It is almost certain that the second and third of these three objects can never be fully achieved. It is possible that public taste in flour might change, so that it would not pay to convert the whole of the endosperm into pure flour, that the admixture of a portion of it with bran might give the best result, but for practical purposes it is

certainly true at the present time that these are the three objects at which the miller must aim in all countries if he is to make the largest profit. Let us proceed to consider these different objects in more detail.

Wheat Cleaning.

The most efficient process of flour milling is the removal of impurities from the wheat. In a good modern mill it may be said that for practical purposes this job is done completely, the wheat on the first break is clean and free from dirt, dust and impurities.

This is best tested by the quality of the break flour, where impurities in the wheat quickly show up. In practice, the effectiveness of the work of the different wheat cleaning machines can be judged by the eye by a skilled man, the break flour being the final test.

The only other methods we know of measuring the cleanness of wheat are to shake a known quantity with a measured volume of water, carbon tetrachloride (which gives a rather more definite result), or patent flour. The amount of impurity taken up by the absorbent can then be approximately measured. There is no standard method; in view of the fact that practically perfect cleanness can be obtained, it is probably not worth while working out a standard method of measuring and recording the amount of dirt present.

While the wheat is left clean in a good wheat cleaning plant, yet it is not true to say that the efficiency is 100%, because a certain amount of broken or small grains of wheat is generally lifted out with the small impurities. We have by no means yet reached full efficiency in the elimination of all useful wheat from the small im-

purities, nor in the perfect separation of the different kinds of seeds from one another. In these circumstances research cannot hope substantially to improve the result; all that can be done is to get the same result more cheaply.

It should be understood that we are dealing here with the physical cleaning of wheat, not with conditioning nor with the effect of heat, time and moisture on the strength of the resultant flour.

The operations of the wheat cleaning section are all variations of the following :—

1. Separation by size or shape, either by sieving or by the pocket system.
2. Separation by difference of specific gravity *e.g.* aspiration of light material and the separation of heavy material in the washer.
3. Conditioning, *i.e.* the application of heat, moisture and air for given periods of time.
4. Washing and wet scouring.
5. Cleaning by dry rubbing, *e.g.* scouring or brushing.

Table II., page 18, shows the cost of carrying out these operations in a good modern mill. The way in which the work could be done more cheaply would be by securing one or more of the following :—

Lower initial cost.	Less power.
Lower working cost.	Less repairs.
Less space.	Less dirt.
Greater simplicity.	Less labour.
Greater reliability.	

As the present working cost, including interest and depreciation, is only 8d. per sack of 280 lb. of flour, it is clear from a consideration of the operations involved that the margin for saving is not great; it could scarcely be put higher than, say, 2d. a sack.

The Mill. Mechanical Separations.

In the actual conversion of wheat into flour and offal, we are far from getting the ideal result of converting the whole of the endosperm into pure flour. The American authority Bailey* shows by a series of analyses the average endosperm of Russian and Canadian wheat to be 85%, embryo 2%, and bran 13%. He says "The average roller mill probably does not recover as merchantable flour more than 72% to 75% of the potential 82% to 85% of the flour in the endosperm. Thus about 10% of the kernel which in a perfect separation would be returned as flour, appears in the lower priced offals."

There is, of course, the ultimate possibility of achieving 100% efficiency by some wet process, *e.g.* soaking the wheat, squeezing out the endosperm more or less as a liquid, and then drying and converting it into flour, or even, conceivably, making it into dough direct, as in the suggested Apostoloff system, but at the present time any such process seems a long way off.

Table I shows what the extra value to the British miller would be to-day if out of his wheat he could get 84% of pure flour and 16% of bran, as against a typical present day divide of 72% of flour (of which 18% is straights), 10% fine offal and 18% bran. The advantage would amount to no less than 3/4 per sack if spread over the whole production of flour. There is evidently room here for an immense improvement in the milling process from the monetary point of view.

In compiling this table we have assumed that the whole 84 % extraction would fetch the same price as top patents. We are aware that even if a perfect separation of bran and endosperm could be

*"The Chemistry of Wheat Flour"—C, H. Bailey (page 122).

attained there are other factors which influence the quality of low grade flours, but by far the most important impurity is bran powder and the other factors would not affect seriously the values shown in the table.

TABLE I.

PROCEEDS OF MILLING ONE TON OF WHEAT (AT 1928 VALUES) WITH PRESENT DAY 72% EXTRACTION AND WITH 84% EXTRACTION.

Product	Market value ex Mill	Value produced per Ton of Wheat			
		Extract'n	Amount	Extract'n	Amount
			Shillings		Shillings
Top Patents	42/- per 280 lb.	54% ⎫	181.440		
Straights	40/- per 280 lb.	18% ⎭ 72%	57.601	84%	282.240
Thirds	8/9 p. cwt.	10%	17.500		
Bran	8/- p.cwt.	18%	28.801		
	7/6 p. cwt. (for completely clean bran)				24.006
				16%	
			285.342		306.246

Gain : 7·4% on present proceeds, or 3/4 per sack of 280 lb.

THE MILLING PROCESS.

The milling process consists in its present form of four main sections :

1. Breaking up the wheat by fluted rolls.
2. Grading and purifying.
3. Grinding and flattening on smooth rolls.
4. Dressing.

The aim is gradually to break the wheat down by fluted rolls, converting the endosperm as far as possible into large granular pieces of semolina, and the bran into large flakes ; above all, avoiding the production of bran powder. Then follows

an elaborate process of grading and purifying. The skill of the miller consists in choosing the best available machines and using them to make homogeneous stocks, and continually, bit by bit, separating the bran from the endosperm, the main object being all through to keep the bran in particles large enough and flat enough to be separated from the endosperm. The main improvements in the last forty years have been the better classification of the stocks and gentler treatment effected by extending the roller surface. Improvement in these two directions is probably approaching its practicable limit, and it is very doubtful whether it is possible to produce a substantially better separation than is given by the best mills to-day, except by improving the machinery. We discuss in subsequent chapters the directions in which the best prospects of progress seem likely to be found.

Cost of Milling Process.

An estimate of the present day cost of converting wheat into flour is given in Table II.

The table gives the total actual cost of manufacture from the delivery of the wheat to the cleaning plant, to the sending of the flour to the warehouse, all expenses being included except administration, which varies very much and is difficult to estimate. It will be seen that the total cost is approximately 2/9 per sack, of which just under 1/2 is a capital charge for interest and depreciation and 1/7 the working cost. We estimate that these figures represent average conditions for a good 20 sack plant working 6,600 hours a year. What are the prospects of further improvements enabling us to do this work more cheaply?

TABLE II.

COST OF MANUFACTURE OF FLOUR, IN 1928, ON A TYPICAL PLANT PRODUCING 20 SACKS (280 lb. each) OF FLOUR PER HOUR—ASSUMING THAT IT WORKS 6,600 HOURS A YEAR.

WHEAT CLEANING.

	Cost per sack of flour.
Building (Interest and depreciation at 7½%)	.76d.
Plant (Interest and depreciation at 15%)	2.55d.
Cost of Power	.76d.
Cost of Labour	1.92d.
Cost of Light	.11d.
Coal for Conditioner	.55d.
Water	.12d.
Rates	.19d.
Insurance	.22d.
Ground Rent	.08d.
Repairs	.57d.
Cost per sack	7.83d.

MILL.

	Cost per sack of flour.
Building (Interest and depreciation at 7½%)	1.96d.
Plant (Interest and depreciation at 15%)	8.50d.
Cost of Power	3.57d.
Cost of Labour	7.16d.
Cost of Light	.21d.
Rates	.60d.
Insurance	.71d.
Ground Rent	.22d.
Repairs	1.86d.
Cost per sack	24.79d.

This is pre-eminently the field for milling engineers. It is their job to provide a plant which will give the result at the lowest capital cost and the lowest running charge. We must regretfully admit that in the last forty years very little has been done to reduce the cost. Probably in 1890 the cost per sack, allowing for the difference in value of money, would scarcely have exceeded to-day's cost of 2/9.

Having regard to the nature of the processes, in cleaning the wheat and breaking it down, to the fact that flour milling to-day is carried on by what is certainly a highly efficient and automatic process, and to the fact that the machinery is manufactured in first-class works on as large a scale as the world demand allows, we think it is unlikely that there will ever be a substantial reduction in the cost of converting wheat into flour. On the other hand, if by mechanical means we are substantially to increase the yield of patent flour, it is probable that the cost of the plant will be greater. To give a figure which is nothing but a guess, for the purpose of completing the estimates of possible saving, we might suggest that research and improved design may possibly reduce the cost of manufacture by 6d., from, say, 2/9 to 2/3.

Conclusion.

We are justified, therefore, in concluding that in spite of the relatively high efficiency of the modern flour mill, there is ample room for improvement. It is well worth an effort to develop a real science of flour milling engineering in the hope of building up a more efficient system of flour milling which will ensure perfect cleaning of the wheat and more efficient extraction of flour from the wheat berry, and which will perform these operations more economically than at present.

The following table summarises the facts which we have set forth in this chapter. It shows that the total improvements in the past (excluding the use of chemicals) have been worth about 1/6 a sack and that it is theoretically possible to make further improvements up to the value of 3/6 a sack.

RESULTS ACHIEVED DURING THE PAST 50 YEARS.

Washing and Conditioning	Improvement in Diagram	Total past Improvements
6d per sack	1/- per sack	1/6 per sack

FUTURE POSSIBLE ECONOMIES.

Reduced cost of Production	Increased Value of Products through Improved System (3/4d)	Total possible improvements.
6d. per sack	Say 3/- per sack	3/6 per sack

Most millers will agree, however, that if in the course of the next generation research gives us an advantage, not of 3/6 but of, say, 2/- a sack, it is as much as we can reasonably expect. Even this means on the thirty-five million sacks produced annually in the United Kingdom a gain of about three and a half million pounds sterling per annum. This is a prize which justifies a good deal of expenditure on research both by millers and by milling engineers. It is our hope that this book may do something to indicate the lines along which this result is most likely to be achieved.

Chapter II.

SEPARATION ACCORDING TO DIMENSIONS.

The milling process consists mainly of an elaborate series of separations. There is first the separation of many different kinds of impurities from the wheat, then the breaking up of the wheat berry and the division of the resultant chop, by a large variety of separations, into the final products—flour and offal.

Separations can be made by taking advantage of the different characteristics of the various particles. These may be divided into three main groups :—

(1) Dimensions.

(2) Specific gravity.

(3) Resistance offered by the different particles to the passage of an air current.

The only separation by specific gravity which is carried out in milling practice is the separation of stones from wheat, with which it is not proposed to deal in the present edition of this book. Separations by air current are dealt with in a subsequent chapter. In the present chapter it is proposed to deal only with separation according to dimensions. Such separations may be based on the size, or volume, of the particles, or on one or more of the three dimensions, length, width, and thickness; in other words, on the long, middle or short axis.

There are four types of separation which are in fact made in flour milling practice :—

(*a*) Separation according to volume.

(*b*) Separation according to width, that is according to the length of the middle axis.

(*c*) Separation according to length, or the long axis.

(*d*) Separation according to shape, or the relation between the long and the short axis.

Separation by Volume.

Separation by volume may be noticed whenever a quantity of mixed material such as coal is discharged in a heap. The big pieces tend to roll to the outside of the heap whilst the small pieces pile in a cone in the centre. This is due to the difficulty of balancing large particles on a narrow ledge which may afford perfectly secure hold for a small piece. It is quite evident that the large particle " B " (Fig. I) will roll down the slope whilst the small particle " A " will rest on it. Although this method is not directly used in flour milling practice, the same principle applies when a mixture is shaken on a

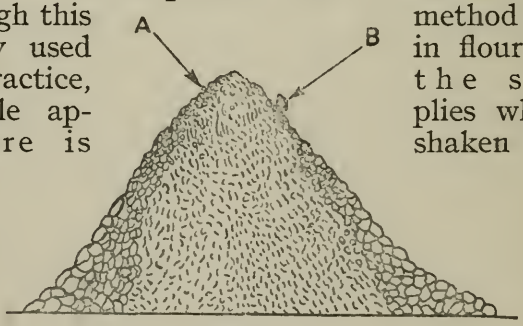


Fig. 1.
Pile of Mixed Material.

sieve. The small particles tend to find their way to the bottom, because they are small and are able

to work their way down through the openings which occur as the big particles are moved about. A very slight movement of the big pieces allows the small pieces to fall through the openings, whereas a much greater movement of the small particles would be necessary to allow a big piece to pass through them. Thus whenever a mixture is shaken, there is a tendency for it to stratify—the smaller pieces below and the larger pieces on top. This stratification takes place even when there is considerable difference in specific gravity ; small particles of light material will, if the agitation is suitable, work down below larger particles of heavier material. This tendency to stratify is very marked in the case of the oscillating sieve, and it is an important factor in adding to the efficiency of this type of separator.

Separation According to Width.

When a mixture of various particles is agitated with some uniform reciprocating motion, the particles tend to arrange themselves with their longest axes parallel to one another. In the case of a reciprocating sieve having the proper speed and stroke, the long axes tend, at a certain point of the stroke, to take up a vertical position as shown later in this chapter. If such a sieve is provided with circular holes, those particles whose middle axes are less than the diameter of the hole will fall through. The separation is therefore made according to the middle axis; it is what is commonly known as a width separation.

Separation According to Length.

The action of a rotary sieve is quite different ; as will be shown later, there is no tendency to up-end the particles, the longest axis tending to

remain horizontal. If provided with round holes, a rotary sieve, therefore, makes a separation according to length.

Separation According to Shape.

Shape is, of course, a very indefinite term, but there is one quality which depends almost entirely on shape, *i.e.* the speed at which a particle will roll down a slope. Clearly, the sphere and the cylinder are the forms which will roll most readily, and, broadly speaking, the greater the difference between its width and its thickness the less readily will a particle roll. This is taken advantage of to effect a separation between wheat and round seeds.

Types of Separators.

The various machines used to effect the separations described above may be divided into four classes :—

(1) Separators of the flat sieve type which may be sub-divided according to the motion imparted to them into—

  (*a*) Sieves vibrating approximately at right angles to their surface.

  (*b*) Sieves reciprocating approximately parallel to their surface.

  (*c*) Rotary sieves.

(2) Separators having a cylindrical or many-sided perforated surface, inside which the stock is fed, and which are rotated round their axes. The simplest example of this type is the reel. The centrifugal is a modification introducing beaters to throw

the stock against the screen; the trieur cylinder is another modification in which the screening surface is replaced by a selective surface which lifts from the stock particles which can be held in the pockets on the surface.

(3) Separators of the disc type, where discs having selective surfaces revolve in a mass of stock and lift out such particles as lodge in the pockets on their surface.

(4) Separators which have no motion of themselves, but present inclined surfaces down which the particles may roll or slide and separate themselves out by the difference in momentum acquired in descending. This principle is sometimes used to effect a separation between stones and wheat.

The Sieve.

Probably the earliest separator was the screen or sieve. The simplest form is that of the stationary inclined sieve frequently used for grading stones, coal, etc. The material to be dressed is flung or allowed to fall on to the upper part of the inclined surface; small pieces find their way through the meshes, and larger pieces slide down without passing through. In this simple form it is evident that the surface must be steep enough to allow the larger pieces to slide down under the pull of gravity and that they will necessarily carry a considerable number of the small pieces with them. If, however, the screen be moved in such a way as to keep the stock on it in a state of agitation, its inclination can be reduced very considerably, and the larger particles will still

be able to travel over it. This, at once, secures several advantages, the most important of which are :—

(*a*) A certain depth of stock can be maintained over the greater part of the screen and subjected to the sieving action for an appreciable time. (*b*) The agitation of the stock causes it to stratify, so that the smaller particles tend to come in contact with the screening surface, thus leading to more efficient use of the screen.

The methods of agitating the screening surface may be divided into three classes :—

(1) Rapid oscillation or vibration, approximately at right angles to the surface. This method is now much used in other industries, but has not yet been successfully adapted to flour milling requirements.

(2) Reciprocating the screen in or near its own plane. This is the common reciprocating sieve and is discussed fully below.

(3) Imparting to the screen a rotary or gyratory motion in its own plane as is done in the plansifter. This class of machine is referred to below as the "Rotary Separator."

The Reciprocating Sieve.

When a particle having greater length than width or thickness falls on to a flat and approximately horizontal surface at rest, it tends to lie with its longest axis horizontal. If, however, the surface on which it rests is reciprocated rapidly in the line of the longest axis, at each change in direction of motion the particle tends to "up end." If, in Fig. 2, P is a body resting on a flat surface AB, it will tend to lie as shown, with its ax

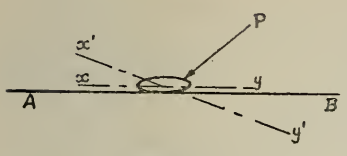


Fig. 2.
POSITION TAKEN UP BY PARTICLE

xy horizontal. If, however, AB be moved rapidly in the direction A, the momentum of P will tend to make the axis xy take up the position of x^1y^1 whilst the speed of AB in the direction A is growing. When the speed of AB becomes constant, xy is again horizontal. But if the speed of AB is suddenly checked, stopped and then reversed, P, which has been gathering momentum and tends to go on moving in the direction A, has its lower side pulled, through the friction between it and AB, in the direction B, and a couple is set up which tends to make the axis xy take up a vertical position. The particle may or may not turn right over. This will depend on its length, the friction between it and the screen, and the action on it of other particles, but if the motion of AB is again reversed the same tendency to up-end will occur at the other end of the stroke.

It is clear then that under proper conditions there is a tendency for the particles to arrange themselves with their longest axes at right angles to the screen at the end of each stroke. If the sieve is reciprocated at a suitable speed, the smaller particles will be shaken down through the larger ones till they reach the screening surface, and will, at the end of each stroke, tend to assume a vertical position allowing those, whose width is not greater than the opening in the sieve, to pass through. Such a sieve should, therefore, have a large capacity and grade according to width.

The Capacity of Reciprocating Sieves.

We have made an elaborate series of investigations into the capacity of the reciprocating sieve under varying conditions as to length of stroke and number of strokes per minute.

The sieve used for this investigation was fitted with a screen having nine holes per square inch, each hole being 5·1 millimetres in diameter. The feed was Manitoba wheat, and the capacity was taken to be the feed when, as nearly as possible, the whole screening surface was covered but no wheat was tailing over.

Some of the results are shown by the curves, Figs. 3 and 4.

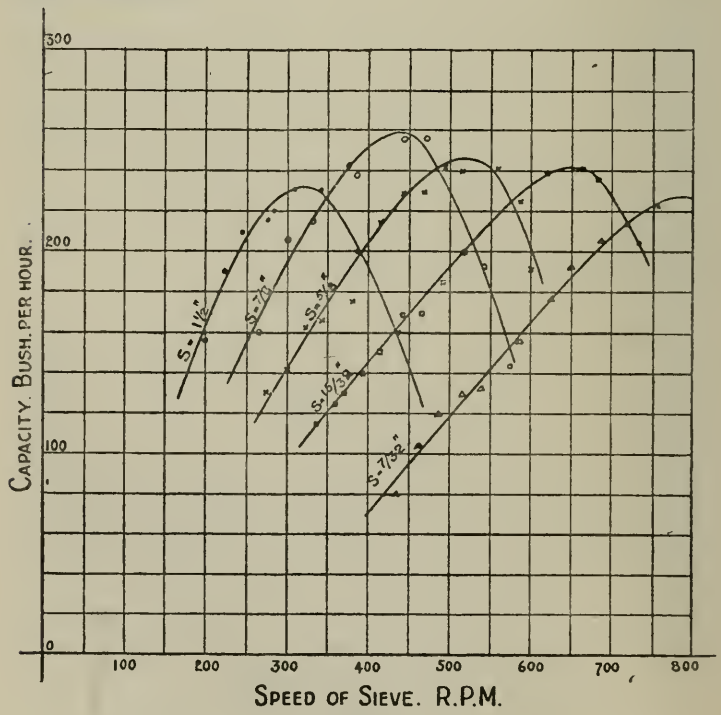


Fig. 3.
Curves Showing Capacity Relative to Speed.

Referring first to Fig. 3, it will be seen that for each length of stroke readings were taken at different speeds. For any fixed stroke the capacity increases up to a certain point in proportion to the speed, the rate of increase then falls off and a maximum is reached, after which a fairly rapid decrease in capacity takes place. The curve shows what is the optimum speed for each length of stroke.

It is interesting to note that, for strokes varying from about ½ in. up to 1 in., there is not much variation in the maximum capacity ; if we go down

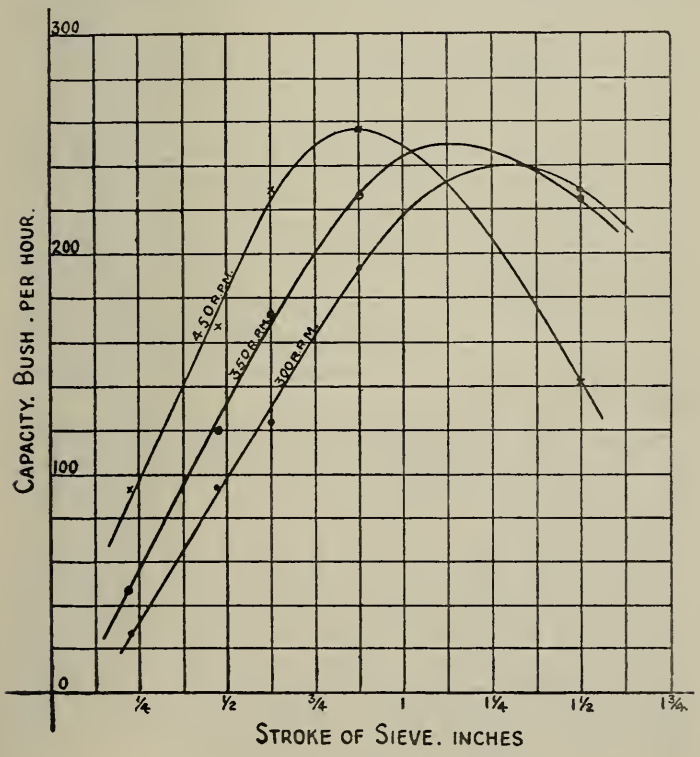


Fig. 4.

CURVES SHOWING CAPACITY RELATIVE TO STROKE.

as low as $\frac{1}{4}$ in. and up as high as $1\frac{1}{2}$ in., the maximum capacity is reduced by about 10 per cent.

For each stroke, there is a range of about 100 revs. per minute, within which something approaching the maximum capacity can be obtained. For instance, with a $\frac{7}{8}$ in. stroke, the speed of the sieve should be not less than about 370 nor more than 470 revs., otherwise there will be a serious drop in capacity.

Fig. 4 shows the variation in capacity plotted against the stroke of the sieve for three speeds, viz. 300, 350 and 450 r.p.m. It will be noted that as the length of stroke is increased the capacity of the sieve increases at first rapidly, then less rapidly till maximum capacity is reached. After that, a further increase in stroke results in a decrease of capacity. For example, at 300 r.p.m. the increase of capacity due to lengthening the stroke from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. (viz. by $\frac{1}{4}$ in.) is 65 bushels per hour, whereas further lengthening the stroke by $\frac{1}{4}$ in. (viz. to 1 in.) results in further increase of capacity of only 55 bushels per hour. Still further lengthening the stroke results in an even lower rate of increase of the capacity and maximum capacity is reached at about $1\frac{1}{4}$ in. stroke.

It will also be noted that at higher speeds the maximum capacity is reached at shorter strokes, $1\frac{1}{8}$ in. in the case of 350 r.p.m. and $\frac{7}{8}$ in. in the case of 450 r.p.m.

Apart from the important matters of speed and length of stroke there are many other almost equally important factors in all sieving operations, as for example, size and shape of screen aperture in relation to the average size of particle in the stock treated, the composition of the stock itself, the shape and texture of its particles and their liability to clog the screen.

Adequate consideration of all these factors would require volumes and we can only give here one or two detached but definite conclusions arrived at as a result of a great number of experiments made with Manitoba wheat.

(1) It was found that variations of slope of the screening surface between one in six and one in twelve had very little influence on the capacity of the sieve.

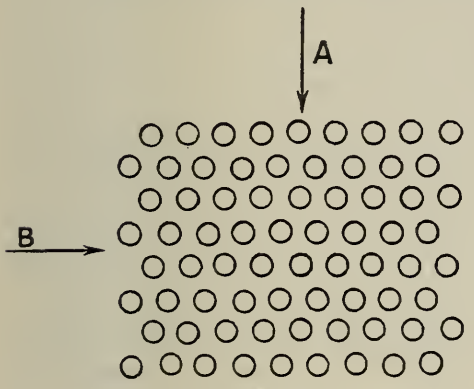


Fig. 5.
PERFORATED HOLES IN SCREEN.

(2) The way in which screens with round holes are fixed in the sieve has a marked effect on capacity. Such screens are usually perforated as shown in Fig. 5, *viz.*, with the holes in line in one direction and staggered in the other direction. It was found that, by arranging the screen in such a way that the grain travelled across the sieve in the direction of the arrow A, Fig. 5, the capacity was about 10% more than when the screen was turned at right angles so that the grain travelled in the direction of the arrow B.

(3) Several tests were made in which the ratio of length to width of the screening surface was varied. These showed that the capacity per sq. ft. of screening surface was constant whether the sieve was long and

narrow or short and wide. There was no indication that the work done was superior in either case.

Separators with a Rotary Motion.

If instead of a reciprocating motion we impart to a horizontal screen a rotary motion in a horizontal plane, particles lying on it tend to move with it. If there were no friction between the screen and the particles lying on it the screen would move whilst the particles stood still; relatively to the screen itself the particles would move in a circle equal to that in which the screen moved. If the friction between the screen and the bodies lying on it is sufficient to overcome their inertia they will move with the screen, that is to say there will be no motion relative to the screen. To obtain the maximum agitation of a mass of particles on such a screen there must be a balanced relation between (*a*) the friction of the stock on the screen, (*b*) the weight of the stock, and (*c*) the velocity of the screening surface. It is well recognised in practice that there are different optimum speeds for different stocks on sieves of this type which cannot be far departed from without great loss in sieving efficiency. But, even with maximum agitation, the stock is never subjected to the violent reversals of motion which occur in a reciprocating sieve. If the motion is uniform and always in the same plane, there is no reason why particles should arrange themselves with their longest axes vertical. They skate over the screening surface, following, but lagging behind its motion. They may roll over, as does a car when asked to negotiate a curve too quickly, but they do not up-end as a car would do if suddenly stopped by striking something well below its centre of gravity.

For this reason separators having a rotary motion are not suitable for grading according to thickness or width. A thin and narrow particle will skate over a hole as readily as a thick and broad one if it is long enough. Separators of this type are, therefore, essentially length or longest axis graders. Because of this, as well as because the agitation to which the stock is subjected is less violent than in the reciprocating sieve, they do not have anything like the same capacity per square foot of surface if capacity is measured by the quantity passed through a screen with a given size of hole. Owing to a rotary separator grading according to greatest axis, the throughs from it are finer than are the throughs from the same screen used on a reciprocating sieve, or from any separator which grades according to thickness or width.

Separators with a rotary motion are not now widely used for grain cleaning but as plansifters they are much used for scalping.

Cylindrical and Many-sided Separators.

Reels.

The simple reel in which the screen is formed into a cylinder or a polygon and rotated about its axis, imparts the necessary agitation to the stock fed into it by lifting it up so far and allowing it to fall back again.

It will be noted that the tumbling of the stock in a reel tends, as in discharging coals, to work all the large particles to the outside of the heap. The smaller particles, when raised to the point A, (Fig. 6), find their way more or less vertically down to B, whilst the larger particles roll down to C. Thus the really effective part of the screen is only that represented by the arc

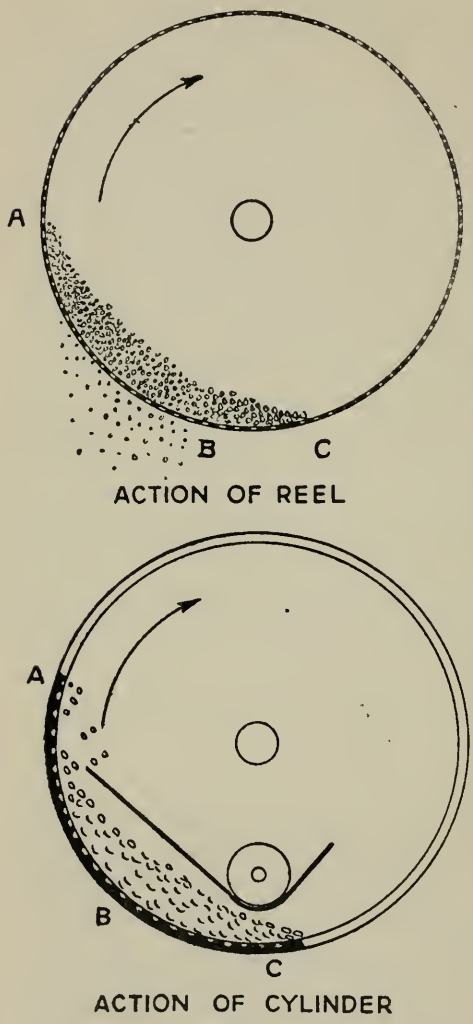


Fig. 6.
ACTIONS OF REEL AND CYLINDER.

AB and is in such a position that it is more difficult for particles to pass through than it would be were the screen horizontal or in the position represented by the arc BC. The capacity per square foot of screen - surface is, therefore, very low.

In order to get the stock to travel from one end of the machine to the other, a reel has to have its axis inclined to the horizontal, and this introduces unwelcome complications in the driving mechanism. In spite of these disadvantages the reel is still used in preliminary wheat cleaning, particularly in the removal of large foreign bodies and sand. For such comparatively

easy separations it does good work and its cheapness is a great recommendation.

Centrifugals.

To meet the inherent disadvantages of the simple reel, and to increase the effective screening surface and to convey the stock from one end of the machine to the other, beaters were introduced to lift the stock and distribute it over practically the whole surface of the screen by centrifugal action. As the beaters convey the stock slowly along the length of the reel it is possible to have the axis of the machine horizontal. The machine thus evolved—the centrifugal—plays a very important part in flour dressing, but it is seldom used in the cleaning of wheat.

The Trieur Cylinder.

This machine has, in the past, been largely used in wheat cleaning. In it the screen is replaced by a metal cylinder inside which pockets or indentations are formed large enough to receive and hold such small particles as have to be removed from the stock. This machine is too well known to require detailed description.

Its action is shown by Fig. 6. Small particles which find their way into the pockets are carried up and discharged into a spiral conveyor fitted below the centre of the cylinder. The larger particles overtail at the end. To ensure the stock travelling from end to end, the cylinder is set with its axis inclined to the horizontal. The action on the mass of the stock is similar to that taking place in a reel. The largest particles tend to roll down the slope from A to C, whilst the smaller tend to pile up within the segment AB. The working part of the surface is, therefore, represented by the arc AB.

One interesting and important feature of these cylinders is the speed at which they are worked. It is quite evident that capacity will depend on the speed, but if this is increased beyond a definite limit, the grain will be held against the circumference of the cylinder by centrifugal force and nothing will fall into the internal conveyor.

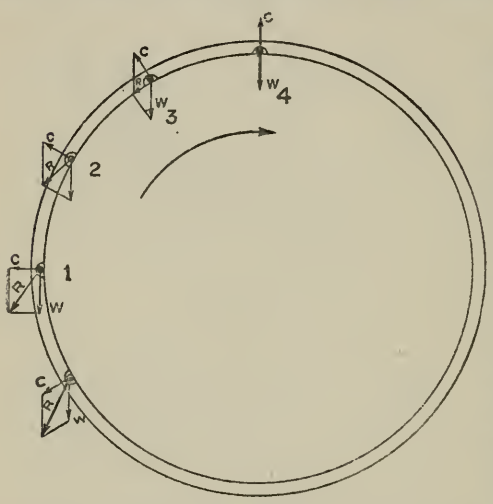


Fig. 7.
FORCES ACTING ON A PARTICLE IN A CYLINDER.

The maximum speed at which a cylinder can be driven must be less than that speed at which the centrifugal force acting on a particle is equal to the force of gravity tending to pull the particle from a pocket at the highest point of the cylinder. In Fig. 7 the forces acting on a grain in different positions in a cylinder are shown.

The positions are marked 1, 2, 3 and 4. The force of gravity tending to pull it down, *i.e.* the weight of the particle considered, is represented by W. Centrifugal force, acting always radially is represented by C. In the diagram C has been taken at three-quarters of W, and it will be seen that whilst the resultant R of W and C tends to keep the particle in the pocket at positions 1 and 2, at position 3, there is no force tending either to hold it in or to throw it out. At position 4,

W being greater than C, and acting in the opposite direction, the particle must fall out.

The relation between the radius of any cylinder and the speed at which it must be driven so as to have W and C equal is given by the formula :—

$$N = 54{\cdot}19 \times \frac{1}{\sqrt{R}} \quad *$$

where N = the number of revolutions of the cylinder per minute

R = the radius of the cylinder in feet.

This formula gives the following speeds at which gravity and centrifugal force are in equilibrium in cylinders of various diameters.

Dia. of Cylinder.	Revs. per Minute.
12 ins.	76
15 ,,	68
21 ,,	58
24 ,,	54
30 ,,	48
36 ,,	44

Particles in the pockets should, theoretically, drop out at speeds just below those listed, but other factors such as friction against the sides of the pockets and slight wedging action tend to prevent their falling and it has been usual to run cylinders at much lower speeds on this account Lower speeds have also been found necessary because of the difficulty of picking up.

On referring to Fig. 8 it will be seen that if the pockets in the cylinder have their axes radial, or approximately so, particles in contact with the surface between the points A and B (where small particles tend to collect) will not enter the pockets unless their diameter is much smaller than that of the pocket. If, however, the pocket is shaped

*For deduction of formula see Appendix I.

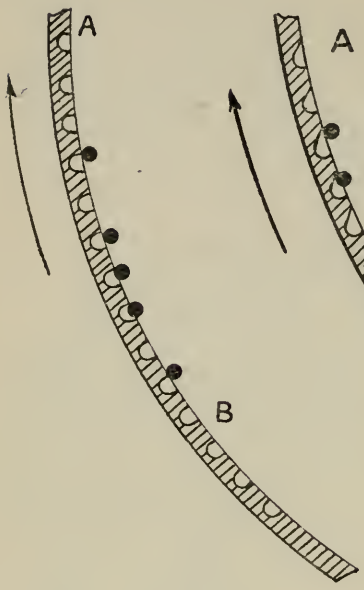


Fig. 8.
SEGMENT OF CYLINDER WITH POCKETS RADIAL.

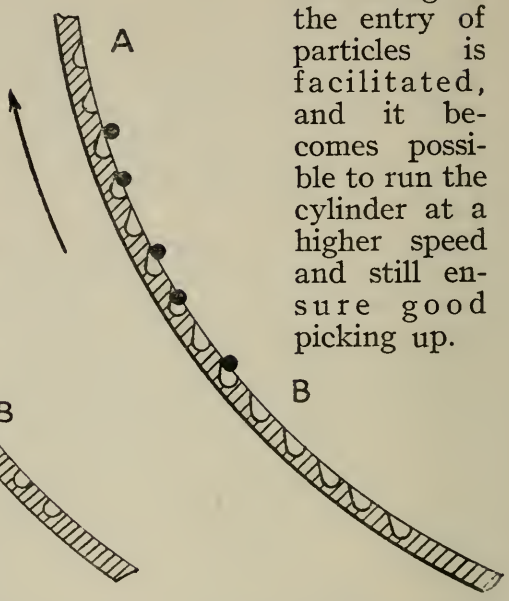


Fig. 9.
SEGMENT OF CYLINDER WITH POCKETS INCLINED.

as in Fig. 9 the entry of particles is facilitated, and it becomes possible to run the cylinder at a higher speed and still ensure good picking up.

Makers of trieur cylinders have recently constructed cylinders which can be run at nearly the maximum speeds at which it is possible to discharge grains.

The following table shows the actual working speeds of cylinders of the old type, speeds of cylinders of the new, or high capacity type, and the speeds at which centrifugal force and gravity are equal.

CYL. DIAM. INS.	REVS. PER MIN.		
	Old Type.	New (HC) type.	Theoretical Max. C=W
16½ ins.	14/16	48/60	65
20 ,,	12/14	44/50	59
24 ,,	10/12	40/45	54

One of the essentials of good work in a Trieur of the slow speed type is a comparatively thin body of grain on the inside of the cylinder. If there is too much stock carried by the machine much of it lies dead and many small grains are unable to get into contact with the selective surface. When the speed of the cylinder is increased it is found that, with the contents of the machine such as are necessary in the case of a slow speed, the stock is so violently agitated that an efficient separation becomes impossible.

In order to reduce this agitation, some makers introduced a complicated system of baffles to hold the grain up against the cylinder walls and to confine the bulk of it between fixed limits. These baffles, however, added enormously to the power required to drive the machine and tended seriously to damage the grain. They have now been generally dispensed with, and the violent agitation of the grain has been damped down by having a much greater mass of stock in the cylinder.

The method of securing this generally adopted is the simple one of reducing, or eliminating, the inclination of the axis of the cylinder. In other words the stock is retained in the cylinder for a relatively longer time. Horizontal cylinders, however, are not self-emptying and for certain purposes, such as seed cleaning, this is a distinct disadvantage. Some makers, therefore, continue to build high capacity cylinders with their axes inclined slightly.

It should be noted that the separation effected by cylinders is essentially a length or maximum axis separation. Grains which are long and thin may enter pockets but if they project beyond the edge of the pocket they are pulled out again by the friction of the mass of grain in the body of the machine. Even when they enter the pockets

only just before these have drawn clear of the bulk of stock, they overbalance and fall out of the pockets earlier than do those particles which are fully embedded. It is quite evident that this tipping out of long grains which have entered pockets cannot take place freely if the pockets are simply shallow cylindrical holes. For this it is necessary that the pockets be shaped as shown in Fig. 10.

Pocket shape has a marked effect on both the capacity and the efficiency of cylinders but, for manufacturing reasons, it is difficult either to drill or to press pockets of the most suitable shapes. Generally a compromise between the most suitable and the most easily manufactured shape has to be arrived at, and for this reason the efficiency of cylinders is less than it would be if perfectly shaped pockets were practicable.

Disc Separators.

Disc Separators were introduced in 1920, and in the arrangement of their separating surfaces are a departure from and improvement on previous practice.

The principle is that of a number of discs with pocketed or indented sides revolving on a horizontal axis in the body of the machine containing the stock to be separated. Particles which are small enough to be accommodated in the pockets are lifted above the mass of grain in the machine and discharged into small catch troughs placed between the discs on the side where their motion is downwards.

Fig. 10 shows a cut-away view of this machine and gives a good idea of its action. The central spokes of the discs are inclined or have attached to them inclined plates which act as propellers

carrying unlifted grains from disc to disc, until at the tail end all unlifted grains are discharged through an opening in the tail end plate. It will be seen that the indented surfaces working in the grain have a large area and that the action is such that the stock is subjected to an effective turning over, resulting in all small particles being brought in contact with the discs. These considerations alone would ensure for disc separa-

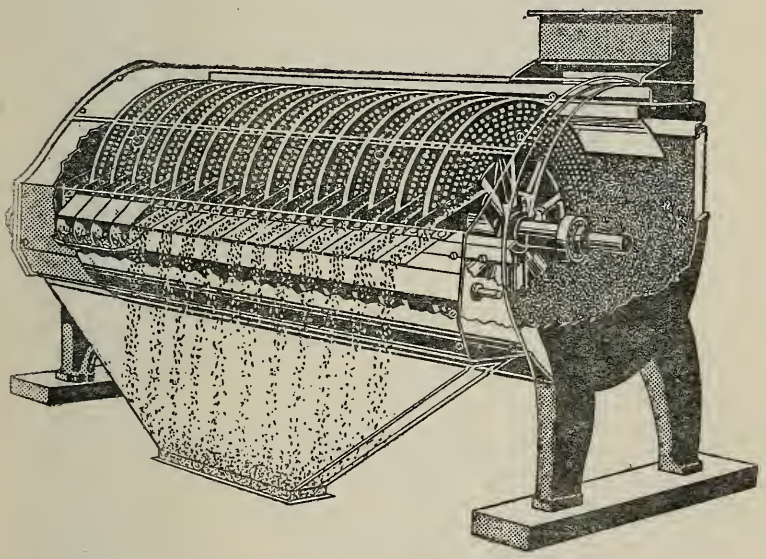


Fig. 10.
"Carter" Disc Separator, Showing Internal Working.

tors high efficiency and big capacity for the space occupied, but there are other important advantages of this type of separator which it may be of interest to note.

(1) The discs can be cast from very hard iron capable of withstanding the abrasive action of the stock.

(2) The pockets or indents can be made almost any shape, and it is possible to make an indent which will not only lift and hold a particle of any given size, but, when the time comes, discharge it freely.

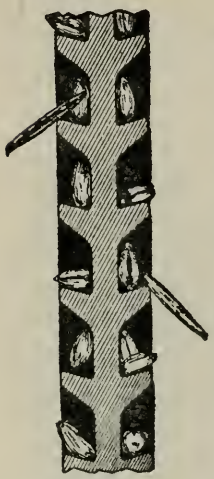


Fig. 11. INDENT IN DISC SHOWING UNDERCUT.

Invariably, disc indents are made with a slight "undercut" as shown on the illustration Fig. 11. This is a great advantage in picking up and retaining. The same illustration shows that the top of the pocket can be sloped away so as to permit of easy discharge.

(3) The discs can be run at a high speed. Indeed it is necessary for the efficient working of the machine that the discs should be run at a speed approaching or exceeding that at which gravity and centrifugal force are equal in a pocket when at the highest point of its path. This high speed gives the machine a large capacity.

(4) As will be seen from Fig. 10, the stock lifted by the discs may be delivered either direct to the liftings hopper or to a worm by which it is carried back to the head end of the machine. This arrangement enables the liftings of any particular disc to be returned for re-treatment. Generally, the liftings of the last few tail end discs are so returned. This possibility of re-treatment increases the flexibility of the machine.

The separation effected by the disc machine is essentially a length separation. Particles which are too long to be completely accommodated in

the pockets are either dragged out in passing through the mass of stock or fall out before they are raised high enough to discharge into the catch troughs. (See Fig. 12).

Fig. 12.
SHOWING LARGE PARTICLES FALLING FROM DISC SEPARATOR.

If the pockets are shallow, very thick short grains may tend to behave in the same way owing to their projecting over the edge of the pocket. It is, therefore, essential that the depth of the pocket should be such as will accommodate completely the thickest grains required to be lifted.

A very great variety of pocket shapes have been devised for different purposes. Some of these are shown in Fig. 13. Each shape is made in several different sizes, and there is therefore a very wide range from which to select the pocket most suitable for the work to be done.

The probability of under-sized particles finding their way into pockets is of vital importance. It is evident that this will depend on :—

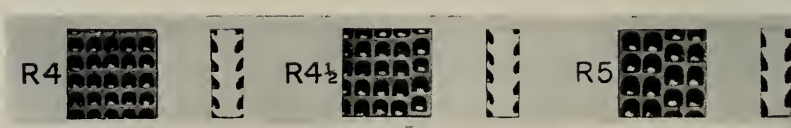
Oats and Barley from Wheat.

Cockle from Wheat, Barley or Oats.

Recockler.

Cockle and Vetch from Wheat, Barley or Oats.

Half Corns from Barley.



Broken from Whole Rice.

Fig. 13.

"CARTER" DISC SEPARATOR. VARIOUS POCKET SHAPES.

(*a*) The number of pockets in the machine.

(*b*) The number of revolutions per minute made by the discs.

(*c*) The volume of stock in which the discs move.

(*d*) The extent to which the stock is turned over and agitated, and

(*e*) The rate of travel of the stock from end to end of the machine.

The number of pockets on each disc is fixed by considerations of the size of pockets, and size of discs. The speed is fixed, within limits, by the relation between weight of particle and centrifugal force.

It has been found that, for a given feed, the machine gives the highest efficiency when working with the discs as fully immersed as possible in the grain and the level of the grain uniform throughout the length of the machine.

The agitation or turning over of the stock depends on the nature of the stock itself and the distance between the discs. Friction between the discs and the stock tends to carry round the particles lying in contact with the discs. These particles are held back somewhat by friction with the particles more remote from the discs and those by others still more remote. The effect is several strata of particles moving in the same direction but at different speeds, the speed diminishing as the distance from the disc increases. It is evident that if the discs are sufficiently far apart there will be a region where there is no movement and small particles in such a region would have no opportunity of being lifted out. On the other hand, if the discs are too closely spaced the friction between them and the stock is sufficient, at a suitable speed, to carry the

whole mass of stock round, and a separation becomes impossible. The most suitable speeds and spacings for all stocks commonly handled have been ascertained.

The very large selective surface passed through the stock by the disc separator gives it a very high capacity in relation to the space occupied. For the same feed it requires only about one eighth the space required by slow speed cylinders.

The exactness with which it is possible to make the pockets or indents for different stocks and the great range of shapes which can be made render possible very exact separations. These considerations alone make this machine a very valuable addition to the means available for effecting a separation according to dimensions.

Practical Application.

Turning now from consideration of the principles underlying separation, it may not be out of place to note, very shortly, the various machines in which these principles are applied in preparing wheat for the mill.

Wheat as received may contain many different impurities ranging from straws and large stones to small seeds and fine sand. All these have to be got rid of before it can be sent for final cleaning.

The first process is the elimination of easily separated foreign matter such as straws, big impurities and fine sand. As has been indicated this is sometimes done in a reel but more often it is done by means of a reciprocating sieve forming part of a receiving separator designed to remove dust and light impurities by aspiration as well as to separate according to dimensions.

The Receiving Separator usually effects four separations by means of three screens contained in the sieve.

(1) Large foreign bodies such as straws, big stones, etc.

(2) Foreign matter which is smaller than (1) but larger than wheat.

(3) Wheat and particles of similar dimensions.

(4) Sand, small seeds, dust, etc.

Wheat from the receiving separator is usually re-treated on another similar machine having somewhat finer covers to effect a closer separation. But, as we have seen, the reciprocating sieve grades according to thickness or width and it is impracticable to separate by such means impurities like barley and oats or cockle and other small seeds having approximately the same thickness as wheat. These must be dealt with by a machine capable of making a separation according to length.

Although the rotary separator does effect a separation according to length, it is not much used for this purpose in wheat cleaning. Until recent years the machine most used was the trieur cylinder. Oats and barley, being longer than wheat, were eliminated by passing the feed through a cylinder having pockets large enough to lift wheat but too small to lift oats or barley. This was followed by another cylinder in which the pockets were too small to lift wheat but were able to lift out small seeds.

Since the introduction of the Disc Separator the use of cylinders has become less common. The more exact separations made possible and the small space occupied by the disc machine

have led to its displacing cylinders to a very large extent. It is usual to employ one or more disc separators to eliminate barley, oats and impurities longer than wheat and another one or more to lift out cockle and other small seeds.

It is inevitable that pieces of broken wheat having the same dimensions as the smaller foreign seeds must be delivered with the latter rather than with the wheat from any machine separating according to dimensions. Where the foreign seeds are more nearly spherical than the pieces of wheat (as is often the case) they may be separated from the mixture by what is known as the Spiral Separator, the principle of which is referred to under (4) on page 25. The same machine may be used to separate round stones from wheat.

Summary.

To sum up, the separations according to dimensions effected in wheat cleaning are :—

(1) Separation according to width or thickness, almost wholly done on reciprocating sieves.

(2) Separation according to length, carried out by means of disc separators or by means of cylinders.

(3) Separation according to shape, effected on spiral inclined planes.

Chapter III.

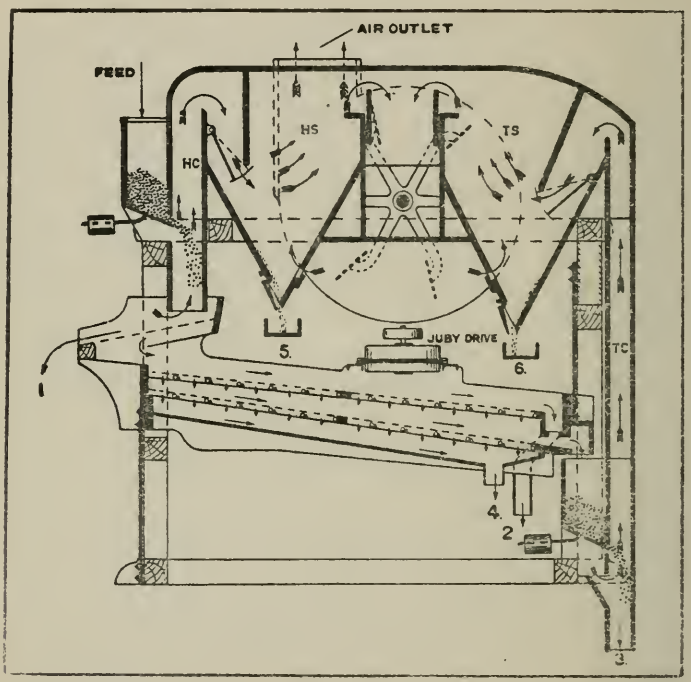
SEPARATION BY AIR CURRENTS.

The separation of impurities from wheat by means of air currents has been common practice in flour milling from the earliest times. We propose in this chapter to confine ourselves to the aspiration of wheat; that is, the use of air currents, with the object of removing from the wheat both dust and other impurities such as chaff, straws, light berries, etc.

Fig. 14 is an illustration of the typical separator which is used all over the world as the first machine for cleaning wheat. It consists essentially of a set of unenclosed oscillating sieves, and of a head and tail aspiration. The primary purpose of the head aspiration is to remove the dust from the wheat before it comes on to the open sieves, where it would otherwise seriously contaminate the mill atmosphere. At the same time, as much chaff and other impurities as possible, are removed. The tail aspiration has the primary object of removing such chaff and heavier impurities as have not been removed by the head aspiration or have been shaken loose while the stock was passing down the sieves.

It will be observed that owing to the form of the machine the vertical channel in the feed aspiration HC is necessarily very short, while the vertical channel in the tail aspiration TC is necessarily very long. We shall show later on that the one is too short for full efficiency, and in the other the distance between the feed plate

and the settling chamber is too great. To make the head aspiration longer would entail an unduly high and expensive machine; to raise the feed plate of the tail aspiration would again involve



Outlets :

1. Strings, Straws, etc.
2. Other impurities larger than wheat.
3. Wheat.
4. Impurities smaller than wheat.
5. Light impurities from feed aspiration.
6. Light impurities from delivery aspiration.

Fig. 14.

Diagram of Separator.

complication and expense. It is therefore the invariable practice to make these aspirations roughly as shown in the diagram, full efficiency

being, to some extent, sacrificed to the needs of a practical engineering design.

There are four main component parts of an aspirating system:—

(1) The separating channel (HC and TC Fig. 14).

(2) The settling chambers (HS and TS, Fig. 14).

(3) The dust collector.

(4) The fan.

We propose now to consider in detail the design of the separating channel and then of the settling chamber. In the following chapter we shall deal with the dust collector. The design of the fan is a matter which is dealt with in many well-known text books, and will therefore not be further referred to here.

The Separating Channel.

By far the most important point in an aspirating system is the design of the separating channel. The object, of course, is to produce a channel in which all particles with less than a certain terminal velocity * will be carried away by the air current whereas all particles with more than that terminal velocity will remain with the bulk of the wheat. Nothing even approaching this result is theoretically or practically possible. A short consideration of the behaviour of air currents in a channel, and of the behaviour of wheat on the one hand, and of the impurities in wheat on the other, when acted on by an air current, will make this abundantly clear.

In the first place, it is as well to point out that the air current which effects the separation may theoretically be at any angle from horizontal to

*For definition of terminal velocity and general theory of separation by air resistance, see Appendix II.

vertical. Owing, however, to practical considerations, it is the universal practice to use vertical air currents, and it is unnecessary to consider here any other type.

Elementary considerations also make it clear that the air channel must in plan be long and narrow. In order to minimise the effect of interference between the particles, and to allow the air to act evenly on each particle, the grain must be introcuced in a single layer with as much space as possible between the individual berries. This necessitates a long feed device on one side of the channel.

Cheapness of construction and economy in power make it important to use as little air as is consistent with efficiency. The channel must therefore be narrow. In other words, it must be an elongated rectangle of the type which is in fact invariably used.

Having said so much by way of preliminary introduction, let us now proceed to consider the three difficulties in the way of obtaining accurate separation.

Irregularity of Air Flow.

Fig. 15 shows, in plan, the air velocities at different points in two air channels.

A is taken from an actual working machine; B is a very carefully designed channel which we believe is as good as can be obtained. It will be seen that in A the distribution of the air is extraordinarily erratic, with regions of high and low velocity in all sorts of unexpected places. In three spots, where the letters Neg. appear, there is an actual reverse velocity.

B, it will be seen, is very symmetrical, with high velocity in the centre and a steadily decreasing

velocity towards the walls, and still more towards the corners. Even with so good a channel as this, it is clear that if impurities in the high velocity area get across to the walls, many of them will fall back; if they get to the corners a still higher proportion will fall back.

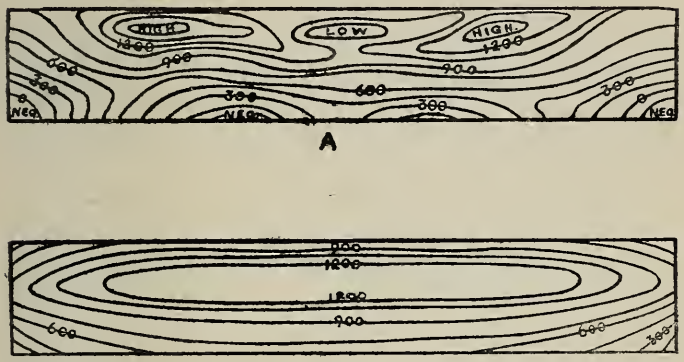


Fig. 15.

AIR VELOCITIES AT POINTS IN AIR CHANNEL (A. AND B)

DANCING BERRIES.

Appendix II gives the general theory of separation by air resistance. It shows that wheat berries, which are fairly symmetrical bodies, are apt to be lifted by a uniform air current if they take up a certain position; they then tend to get into another more stable position and fall back. The effect of this can be clearly seen in the form of "dancing berries," in any aspirator which is fitted with a window. A large proportion of the wheat is lifted a certain number of inches by the air current, dances about for a time, changes its position, and then falls and is carried away by the wheat stream.

Another important point is the tendency, as shown in the appendix, of all bodies to move obliquely across the wheat stream. This means that wheat berries lifted up by a central high velocity aspiration will tend, to some extent, to move across towards the sides of the channel where the velocity is less, and therefore to fall back into the wheat stream. It is, however, important to note that the tendency for this oblique motion is much less in the case of the fairly symmetrical wheat berries than in the case of the impurities found among the wheat.

Behaviour of Impurities in air current.

The impurities are, generally speaking, less symmetrical than the wheat. They therefore have a greater tendency to move across the current, enter the regions of low velocity, and fall back into the wheat stream. This constitutes one of the most serious difficulties in designing an efficient aspirator.

Design of Channel.

We are now in a position to consider the best design to meet the three difficulties, viz :—

1. The irregularity of the air flow, with high velocity in the centre and low velocity at the sides.
2. The dancing wheat berry.
3. The oblique movement of the impurities towards low velocity areas.

Experience has shown that the best compromise between economy and efficiency is obtained when about one inch of feed length is allowed for every ten to fifteen bushels per hour of grain.

The width of the channel should in no case be less than three inches.

The height of the channel above the point of entry of the wheat must be enough to prevent the risk of any dancing berries being carried over, but should be very little more than this, as every inch of extra height means that a certain number of impurities will move across into the low velocity area and be returned to the wheat stream.

The best way to consider the design is in connection with actual examples, shown diagrammatically in Figs. 16, 17 and 18. The air flow as shown by the arrows n these diagrams, is based on experiments made with model water channels. The arrows indicate the lines of flow and were obtained by observation of the paths of coloured particles introduced into the water stream.*

Fig. 16 shows a channel of the type commonly used at the head end of a milling separator. We have already explained that one is forced, for engineering reasons, to make the channel very short in this case. The main object of this aspiration is to remove dust, and owing to the shortness of the channel, only a fairly light aspiration can be used without serious risk of carrying wheat berries over.

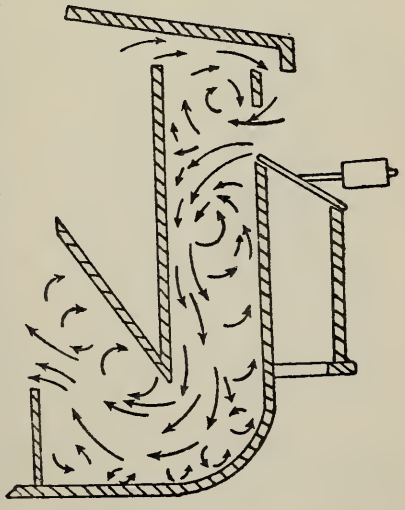


Fig. 16.
DIAGRAM ILLUSTRATING AIR FLOW.

*The conditions under which air currents, eddies, etc., can be examined by means of water flow are well known to physicists. See "Dictionary of Applied Physics"—Vol.I, page 191.

Not only so, but as the arrows show, the flow in the channel is decidedly bad. The channel is, firstly, too short for a smooth flow, and secondly, the opening below the feed plate is too large.

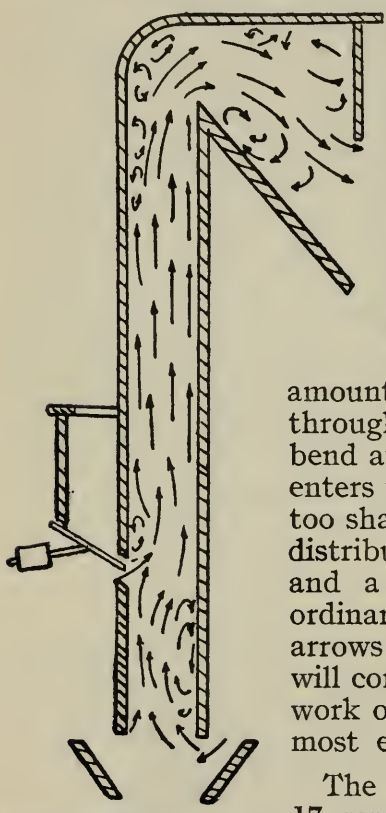


Fig. 17
DIAGRAM ILLUSTRATING AIR FLOW.

The main air is drawn in at this point and causes a marked "dead air" region which occurs above the wheat curtain and extends almost three-fourths of the way across the channel. A further well marked eddy is formed at the foot of the channel and restricts the amount of air entering through the opening. The bend at the top where the air enters the settling chamber is too sharp. Altogether the air distribution is thoroughly bad, and a glance at the extraordinary directions of the arrows in the diagram will convince anyone that the work of this channel must be most erratic.

The channel shown in Fig. 17 represents the type commonly employed on the tail aspiration of milling separators. In this case, owing to necessities of design, the height of the channel above the feed is not too small, but too great. It will, however, be seen that the flow is very much better than in the previous type, and considerably better separation

between the wheat and the impurities is possible.

Fig. 18 represents what we believe to be the most efficient channel that can be designed.

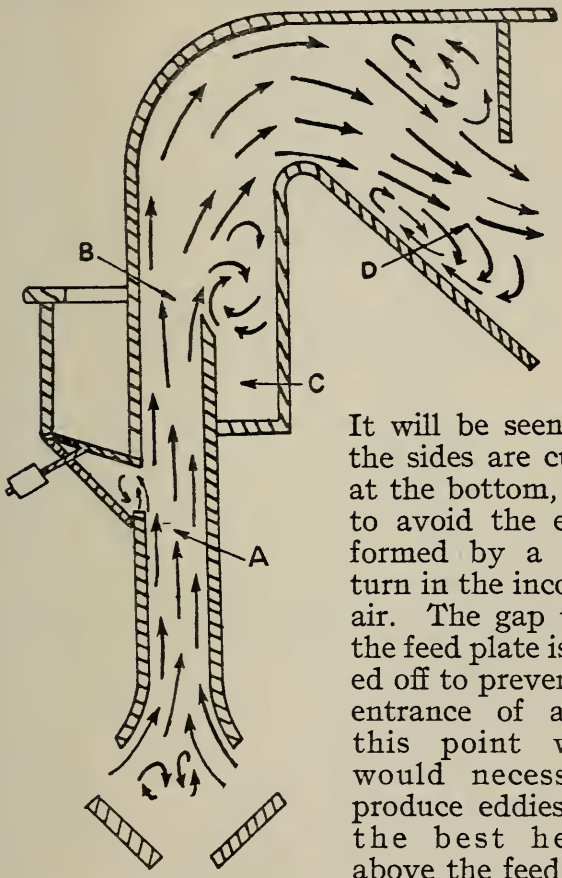


Fig. 18.
DIAGRAM ILLUSTRATING AIR FLOW.

It will be seen that the sides are curved at the bottom, so as to avoid the eddies formed by a sharp turn in the incoming air. The gap under the feed plate is sealed off to prevent the entrance of air at this point which would necessarily produce eddies. At the best height above the feed plate is a preliminary expansion which catches the heavier impurities as soon as the sound wheat berries have fallen back into the wheat stream. Then there is a gradual bend of the channel into the settling chamber. The flow obtained with this

model showed no serious eddies or dead air regions, and designers would be well advised to adhere as closely as practicable to this type.

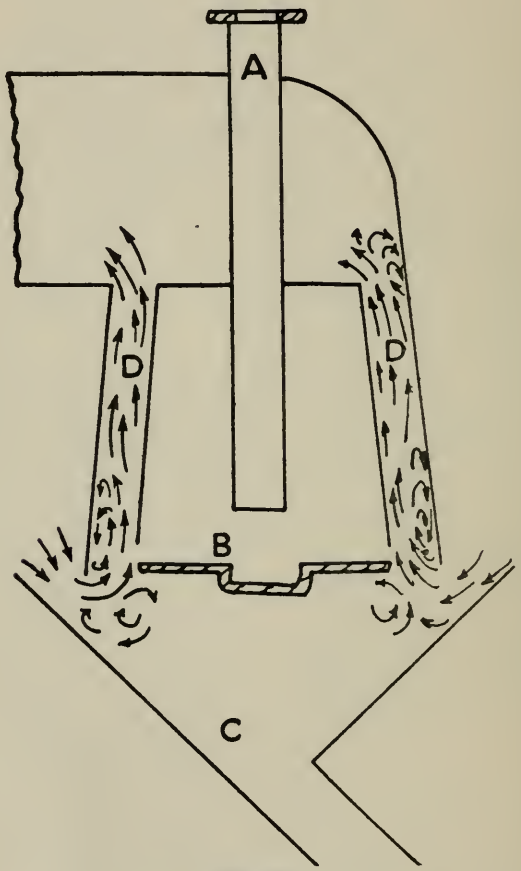


Fig. 19.
Disc Type Aspirator Air Flow.

Fig. 19 shows a quite different type of aspirating channel where the wheat is fed through a pipe A to a central rotating disc B, from which it is

thrown off by centrifugal force, the wheat falling down the hopper C, while the impurities are carried away by a rising air current through the conduit D. It will be seen that the flow here shows the same dead air region due to the sharp angle through which the air is turned on entering the channel. In this case the result is worse because the eddy is on the side of the channel at which the grain is delivered to the hopper, so that any impurities caught in the eddy are almost certain to be carried away with the wheat.

Efficiency of Separation.

It has hitherto not been possible to measure or record the efficiency of a milling aspirator for the simple reason that there has been no definition as to what is meant by the word efficiency. The obvious definition would be the ratio of impurities removed by the aspirator to the total impurities present. This, however, is in practice a useless definition as the impurities may vary from very light impurities, the great bulk of which almost any aspirator would remove, to much heavier impurities only a moderate proportion of which would be removed even by the most efficient aspirator. A bad aspirator might with certain materials, show an efficiency of nearly 100%, whereas a good aspirator under more difficult conditions might show an efficiency not exceeding 50%. We have made a thorough investigation of the whole matter. Everything depends, as we have shown, on the terminal velocity of the products to be separated, and in this connection we have obtained interesting results.

The usual terminal velocities* of wheat are from 2,000 to 2,200 feet per minute ; the highest figure we have found is as high as 2,600 ft. per min. On the other hand, light but usable berries may have a terminal velocity as low as 1,400 ft. per min. ; even those with still lower terminal velocities may contain a useful proportion of flour.

By aspirating large numbers of wheat samples we have found that in practice the velocities used vary from 1,200 to 1,250 ft. per min. The normal may be taken as 1,200 ft. per min. Working at this velocity it is very easy to separate all impurities whose terminal velocities are less than 1,000 ft. per min. The difficulty lies in separating those impurities whose terminal velocities lie between 1,000 and 1,400 ft. per min. Fortunately, relatively few impurities, apart from foreign seeds, that are in practice found in wheat have terminal velocities above 1,400 ft. per min. ; those which have such terminal velocities must be regarded as being in practice inseparable by aspiration.

We find therefore that almost any aspirator will separate the impurities with terminal velocities below 1,000 ft. per min. These must, therefore, be eliminated in considering relative efficiencies. The difference between a good and a bad aspirator depends on the proportion of the total impurities, with terminal velocities between 1,000 and 1,400 ft. per min., which it will separate from the wheat. This therefore constitutes our definition of efficiency :—

The efficiency of a wheat aspirator is measured by the proportion of impurities, with terminal velocities between 1,000 *and* 1,400 *ft. per min., which is separated from the wheat in the process of a single aspiration.*

Even within the limits of this definition it is, of course, easier to separate impurities with terminal

*The terminal velocities were measured on the laboratory aspirator as described in Appendix III.

velocities between 1,000 and 1,200 ft. per min. than those with terminal velocities between 1,200 and 1,400 ft. per min. A test made with a sample where most of the impurities were of the lighter type would give a higher efficiency than a test where the bulk of the impurities had terminal velocities so high as 1,300 and 1,400 ft. per min. We have found in practice, as the result of a large number of tests on varying wheat mixtures, that the efficiency figure obtained on different samples does not vary by more than two to three per cent. This source of error is therefore of no real importance in practice.

Our definition of efficiency of aspiration is admittedly empirical and tentative, but it does, for the first time, make it possible to arrive at a figure which can be recorded numerically, and which enables different experimenters to compare one aspirator with another, and to arrive at approximately the same figures.

Another difficulty which arises in practice is the accurate measurement of the total quantity of impurities present in the wheat. This has to be done by the method of sampling, and it is well known that bulk samples of wheat vary very considerably in composition. We have devised a method of eliminating this source of error by running the same stock through an aspirator two or three times. A simple calculation, given in Appendix IV., shows that if we measure the impurities lifted from the total weight of stock at each run, calling the impurities lifted at the first run A, and those lifted at the second run B, then the efficiency of the aspiration is given by the simple formula :

$$\frac{A-B}{A}$$

This eliminates all uncertainty in measurement of the samples and makes the test an exceedingly simple one.

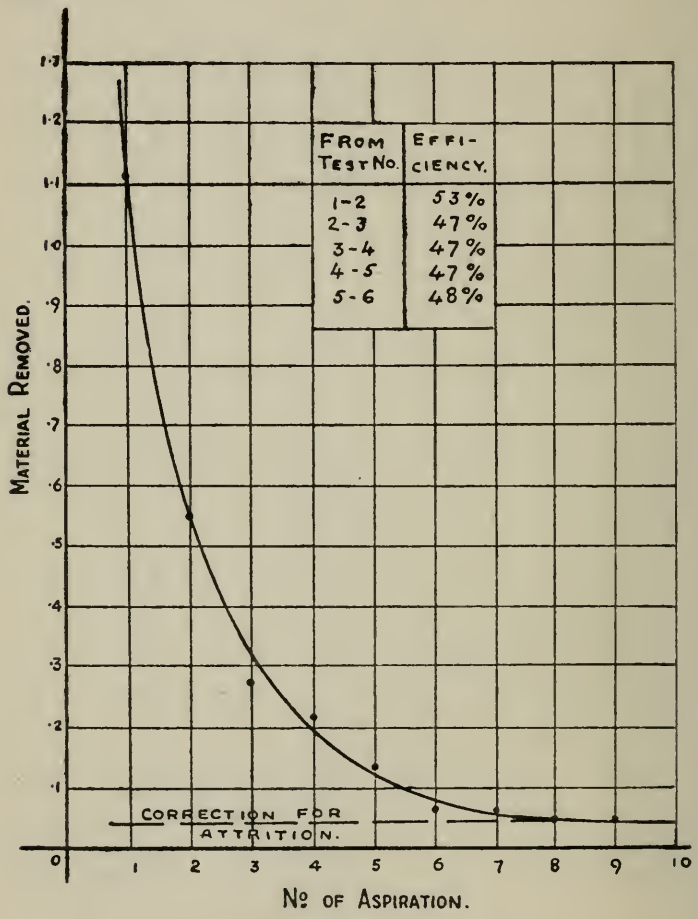


Fig. 20.
CURVE OF ASPIRATION EFFICIENCY.

The only source of error is due to the attrition of the grain in passing round the circuit whereby further impurities are produced. This error is not a very serious one, and, moreover, it has

been found that after a series of tests the amount lifted is reduced to a constant figure representing the new impurities formed, and a fairly accurate allowance can therefore be made.

Fig. 20 shows in the form of a graph the result of a series of tests made in this way. On examining the shape of the curve it will be seen that after the sixth aspiration there was a fixed amount of about 0·04 lb. removed at each succeeding aspiration. This was clearly the amount of light material produced by attrition and it is therefore necessary to deduct this as a correction from each reading. After making this correction the efficiencies were as shown in the small table inset in the figure; as the result of the first two tests the efficiency was 53%, and following tests gave 47%.

One would expect the efficiency to become slightly less with each test for the following reason. In the first test one would expect a larger proportion of the light impurities with terminal velocities round about 1,000 ft. per min. to be removed and a smaller proportion of the heavier impurities. If this were the case the impurities remaining from the second test would have a higher terminal velocity and one would therefore expect a slightly lower efficiency.

The result showing an efficiency of 53% the first time and then dropping to a fixed figure of 47% is a little surprising. No doubt there is some experimental error, because actually the efficiency must have decreased test by test from about 53% to 47%. Broadly speaking, however, it is clear that the efficiency of the aspirator on the stock tested is round about 50% with an error of $\pm 3\%$

In order to test a machine by this method, it is perhaps simplest to have it in a testing station,

but it can quite easily be tested in the mill by simply allowing a certain measured weight of feed to go through the machine two or three times, catching it off after it has passed through and feeding it in again. It is a simple test requiring only the weighing two or three times of the feed, and of the lifted impurities which have terminal velocities of from 1,000 to 1,400 ft. per min.

We have tested a considerable number of machines by the above method. The lowest efficiency we have found was about 30% with a narrow channel with irregular flow. Generally speaking, the efficiency rises as the width is increased up to four inches, but not beyond that. The highest figure we have reached was just over 55%, which was obtained with a channel having a cross section 24 inches by 4 inches, with the feed plate 2 ft. 6 ins. below the entrance to the settling chamber, the channel being extended below the feed plate to give a total length of 6 ft. This channel gives as good a velocity distribution as can probably be obtained in practice. In general, the tests confirmed the theoretical considerations discussed in the preceding paragraphs.

Total Liftings.

It is interesting to consider what portion of the impurities in wheat can be lifted in one aspiration by a good aspirator. An ordinary wheat mixture as used in an English mill, was analysed ; 50% of the impurities had terminal velocities below 1,000 ft. per min. and 50% had terminal velocities between 1,000 and 1,400 ft. per min. As practically all the impurities with terminal velocities below 1,000 are taken out, an aspirator with an efficiency of 55% removes :—

(*a*) All the impurities with less than 1,000 ft. per min. velocity, or 50% of the whole.

(*b*) 55% of the impurities with higher terminal velocities, or 27·5% of the whole.

In all, therefore, 77·5% of the impurities are removed from the dirty wheat in one aspiration. With a wheat like Australian, in which some 70% of the impurities have terminal velocities less than 1,000 ft. per min., 86·5% of the total impurities are removed.

Design of Settling Chamber.

We have still to consider the design of the settling chamber. Its object is to catch the heavier impurities allowing only the lightest to pass on to the dust collector. It is not difficult to make a reasonably efficient settling chamber and, within limits, the design is of no great importance as in any case any impurities missed by the settling chamber will be recovered in the dust collector.

There are, broadly speaking, two ways in which the problem can be dealt with :—

1. In a vertical aspiration the area of the trunk can be increased so as to reduce the air velocity, thereby depositing the impurities in side pockets.
2. The air current may be deflected from the vertical and carried along more or less horizontally until the suspended material has fallen out under the action of gravity.

Both these methods are well illustrated by Fig. 18. The vertical channel A in which the impurities are being carried upwards is expanded to about twice the width at B, in such a way that the eddies tend to carry the impurities into the pocket C, from which they are collected. The lighter impurities are carried on to the settling chamber D, where, partly by means of baffles and partly by reduced velocity of the air, many of the lighter impurities are deposited.

It should be noted that the vertical height is comparatively small; a substantially larger proportion of the impurities would be caught in C if further vertical height were available.

Generally speaking, the vertical expansion method is very little used; almost invariably the air current is turned into a horizontal direction and the necessary deposits are secured by means of expansion and baffles. This is mainly an engineering question, the problem being to fit the expansion chamber into a given machine in the cheapest and most convenient way.

Summary.

The most important point in the design of an aspirator is the separating channel.

Regularity of flow of the air current can be secured by correctly proportioning the length of the channel to its cross section, and by suitably designing the air inlet and discharge.

Dancing berries determine the height of the air discharge above the point at which the grain is fed in.

The oblique movement of the impurities across the air current sets a limit to the narrowness of the channel.

Efficiency of aspiration is difficult to define owing to the great diversity both in the quantity and in the nature of the impurities found in different wheats. A definition is proposed and a method of testing based thereon is described. It is shown that by this method the work of different aspirators can be compared.

The design of settling chambers is chiefly a question of providing adequate expansion space in a given machine.

Chapter IV.

DUST COLLECTION.

The problem of the separation of dust from air is of great importance in the milling industry.

Certain methods which are successfully used in other industries are impossible in milling ; electrostatic devices are not used in this country, owing partly to the danger of fire and partly to their relatively high cost, although a few such devices are at work in flour mills on the continent. Wet sprays, a very effective method in many cases, are impossible in milling because the dust has considerable commercial value, and would have to be dried and recovered ; also the effluent would be unpleasant and difficult to get rid of.

The method mainly used in flour mills in the old days was to blow the dusty air into a large room, letting the air escape slowly while the bulk of the dust settled on the floor. This was an expensive method and very dangerous from the point of view of dust explosions, and it has long since been abandoned.

There remain two methods of dust collection which are used in flour mills throughout the world, the separation of dust by means of centrifugal force, specially in the well-known "cyclone" dust collector, and the method of filtering the dusty air through a textile filtering medium.

The Cyclone Dust Collector.

Centrifugal dust collectors used in the milling industry are almost entirely confined to the

"Cyclone" type. In a few special cases, where centrifugal collectors are incorporated in machines, they are of the dust separating fan type, the principles of which will be discussed in the section dealing with closed circuit machines.

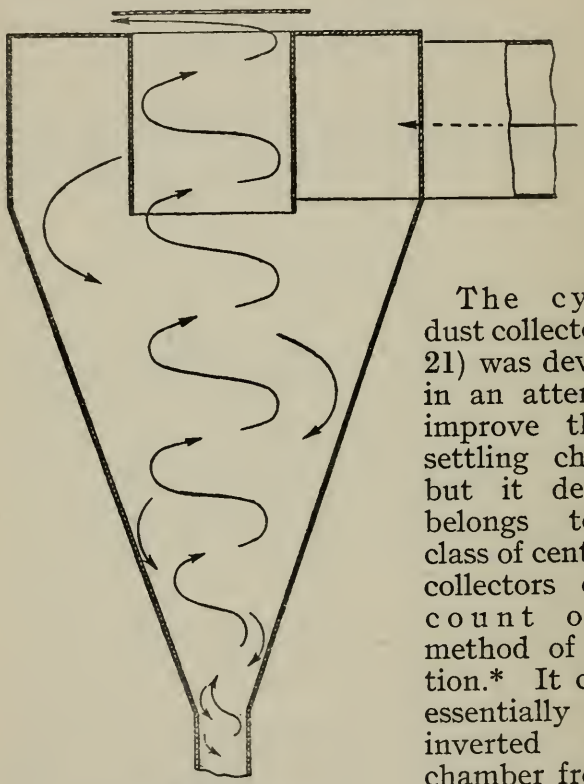


Fig. 21.
CYCLONE DUST COLLECTOR.

The cyclone dust collector (Fig. 21) was developed in an attempt to improve the old settling chamber, but it definitely belongs to the class of centrifugal collectors on account of its method of operation.* It consists essentially of an inverted conical chamber from the bottom of which the separated dust is spouted away. The dust laden air enters tangentially at the top and the clean air is discharged from a cylindrical pipe or thimble passing axially through the top of the chamber and extending inside to a point slightly below the point at which the air enters.

*See Appendix V.

Normally the cyclone is arranged with the axis of the cone vertical, but it is an interesting fact that the separation takes place almost equally well if the axis is horizontal or inclined at any angle.

It is difficult to give a figure for the efficiency of the cyclone. The ordinary mill cyclone of about 8 ft. diameter would have an efficiency varying from 70% to 90%, according to the nature of the dust, that is to say, it would collect from 70% to 90% of the dust, 10% to 30% escaping through the clean air outlet.

A very interesting fact which has emerged from the experiments carried out in our laboratories is that the efficiency of the cyclone becomes higher as the diameter is reduced. With a cyclone 6 inches in diameter the efficiency is comparable with that of the best textile filters, reaching about 99½%.

A new form of dust collector, known as the "Multicone," has been designed, consisting of a large number of these highly efficient small cyclones. Fig. 22 shows the arrangement of such a machine. It will be noticed that the cyclones are arranged with their axes horizontal, so as to facilitate the collection of the separated dust in the conveyors A and B.

The air enters the central chamber CC, which is under pressure, and from that enters each cyclone tangentially in the usual way. From the cyclone the dust is ejected horizontally into the dust chamber D, and, falling to the bottom, is carried away by the conveyor B through a seal. The dust free air emerges from the top of the cyclone into the clean air chamber E, and so away to the atmosphere. Any dust which settles in the chamber C is carried away by the conveyor A.

In the initial stages of development difficulty arose because the air distributed itself unevenly between the different cyclones, tending to go through an individual cyclone in a rush, carrying large quantities of dust with it into the clean air

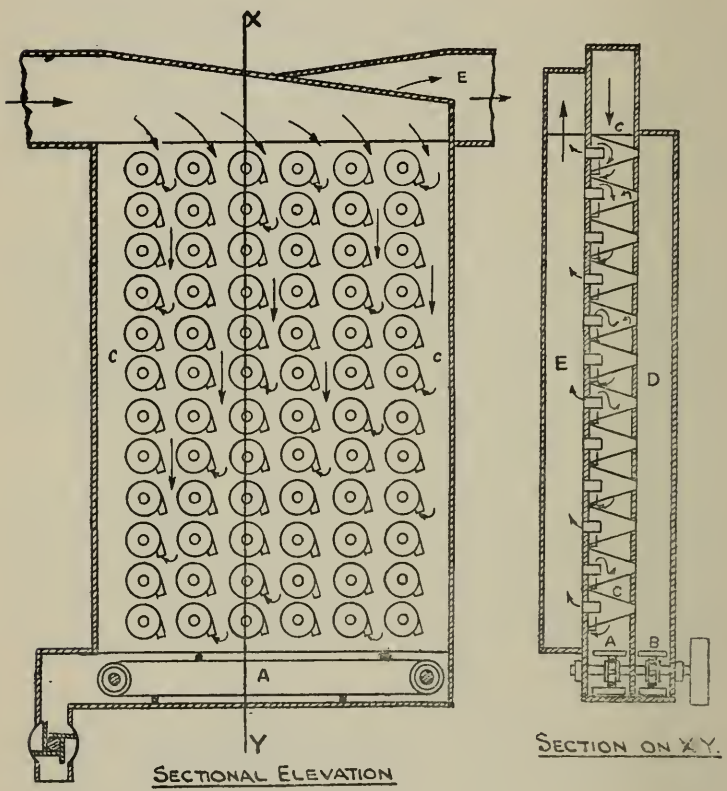


Fig. 22.
"MULTICONE" DUST COLLECTOR.

chamber. It was, however, ultimately found that by proportioning the dust outlet and the clean air outlet from the cyclone in such a way as to make the air pressure in the dust-delivery chamber D, equal to that in the clean air chamber

E, this difficulty was overcome ; each cyclone dealt with its proper quantity of air and the machine worked reliably and regularly.

The obvious difficulty with a machine consisting of such small cyclones is the risk of choking, which, with certain kinds of dust, is likely to be serious. With fairly dry dust this does not occur. The machine is as yet in the experimental stage, though there are a number of them actually at work, giving the high efficiency which had been expected. If this machine should prove a commercial success it will be a very definite development of the old cyclone, and will, to a large extent, combine the efficiency of the best filter dust collector with the advantages of the cyclone, that is to say, cheapness and absence of moving parts.

Filter Dust Collectors.

The Pressure Filter.

The simplest form of dust filter, shown diagrammatically in Fig. 23, is known as a pressure dust collector, because the dusty air is blown into the sleeves under pressure, and escapes through the sleeves to the open air. This machine consists of a vertical nest of sleeves opening at the top end into a common chamber into which the dust laden air is discharged from the fan. The lower ends of the sleeves are also open to a common chamber in which the dust is collected and from which it is delivered by a suitable air-tight discharge seal. The air passes through the sleeves directly into the room. Cleaning of the sleeves is accomplished by means of a grid or lattice, the size of opening of which is somewhat less than the diameter of the sleeves. This grid is moved up and down the sleeves by

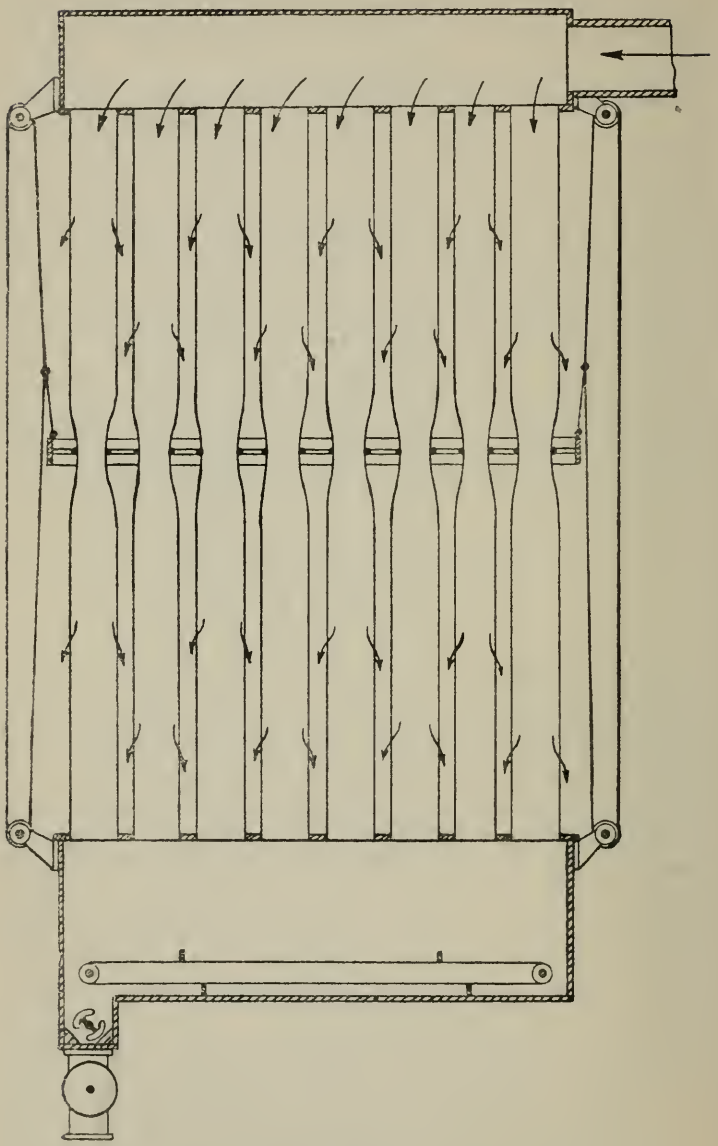


Fig. 23.
PRESSURE FILTER DUST COLLECTOR.

means of endless chains and in its passage dislodges the dust adhering to the inside which falls into the dust collecting chamber.

It is to be noted that the air is continuously blowing outward through the sleeves even while the cleaning grid passes up and down. The dust, therefore, is continuously being forced into the material and a gradual choking inevitably occurs. For this reason, a coarse cloth must be used, which has the disadvantage of allowing a considerable proportion of the dust to escape into the atmosphere. Even so, the pores of the cloth become gradually choked, increasing the back pressure on the fan, and so reducing the draught on the machine from which the air is drawn, and consequently spoiling its work. At intervals it is necessary to brush and shake the sleeves by hand so as to clean them.

This form of pressure dust collector, which is the cheapest that can be constructed, has therefore two grave disadvantages. It allows a considerable proportion of the dust to pass into the room, and by gradual choking, causes irregular working. In other words, the pressure filter is dirty and irregular in its working—the two main faults of a dust collector.

In the United States, the pressure filter has been developed on rather different lines so as to eliminate these faults to some extent. The sleeves are arranged in rows radially round a common axis about which they slowly revolve, like the spokes of a number of wheels side by side. In one of the common forms of filter (Fig. 24), the inlet for the dust laden air consists of a cylindrical duct in the centre of the machine. The inner ends of the sleeves are connected to this, the other ends being sealed. The air passes from the

inlet into the interior of the sleeves and through them to the atmosphere.

At the top of the air inlet duct, and isolated from it, is a dead air chamber so arranged that

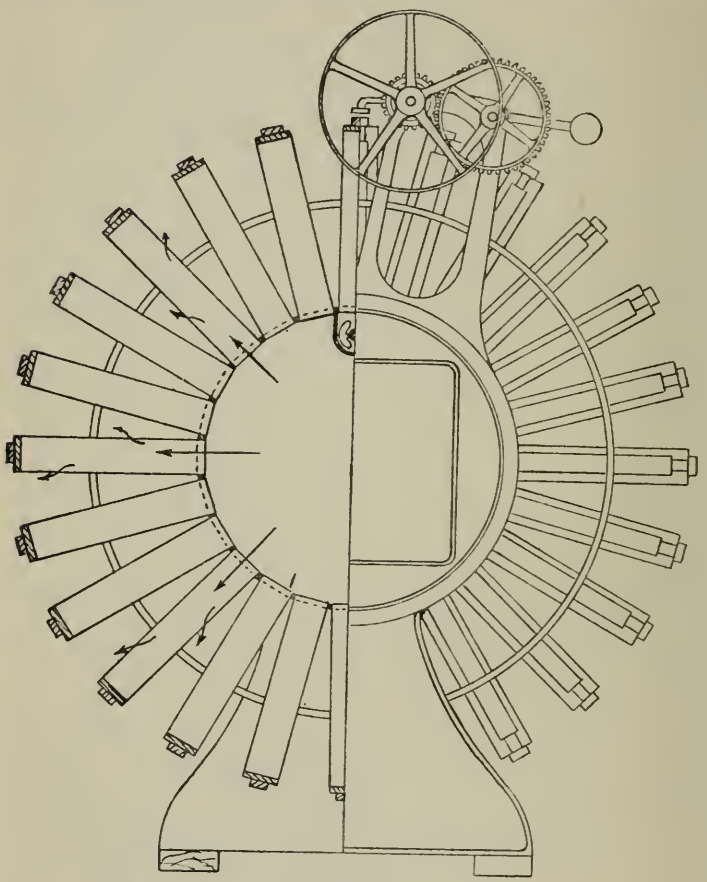


Fig. 24.
AMERICAN PRESSURE FILTER DUST COLLECTOR.

as the sleeves revolve they come in turn vertically above this chamber, and are cut off by it from the pressure of the incoming air. In this position,

while there is no air passing through the sleeves, they are shaken by tapping gear, and so deposit their dust in the dust discharge chamber out of which it is taken by a worm or other suitable means.

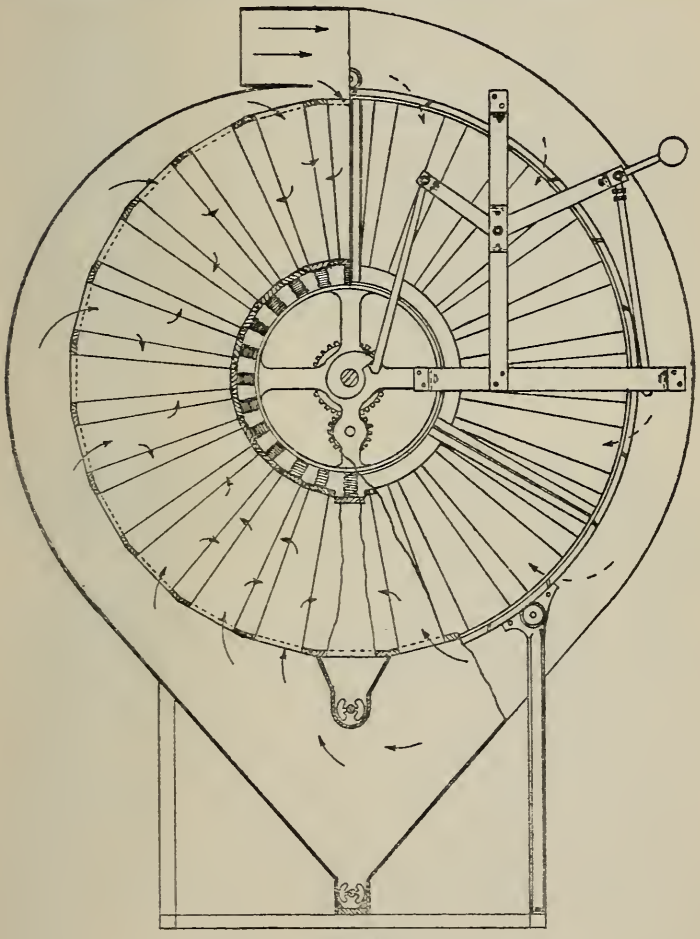


Fig. 25.
AMERICAN PRESSURE FILTER DUST COLLECTOR.

Fig. 25 shows another form of American pressure dust collector, in which the dust laden air is blown

into an annular space round the sleeves. This arrangement has the advantage of making it possible to have conical sleeves, which must clearly tend to make the cleaning more effective.

In these American machines the cleaning is substantially better than in the English pressure type machine; a somewhat finer cloth can accordingly be used. The American machine therefore allows less dust to escape into the mill and causes less irregularity in working. It is, on the other hand, more expensive than the English machine, and it is by no means clean. Like many American machines it is lightly built and some of the moving parts are very inaccessible; in practice a considerable amount of dust is almost always found surrounding such machines.

The Suction Filter.

By far the most efficient type of textile filter is the so-called suction filter, in which the nest of sleeves is contained in a closed compartment which is connected to the suction fan.

Fig. 26 is a diagram of the arrangement of such a machine. The dust laden air passes first into a hopper A, and from the hopper upwards into a number of vertical textile sleeves which are generally about 8 in. in diameter. The air then passes through the sleeves into a closed chamber D and from this away by the clean air outlet E to the fan. The main body of the machine is divided vertically into three or more air-tight compartments, each containing a set of sleeves. By means of a mechanism F the outlet to the fan is at intervals closed, and the compartment at the same time opened to the atmosphere. In this way a reverse air current is drawn from this opening through the sleeves into

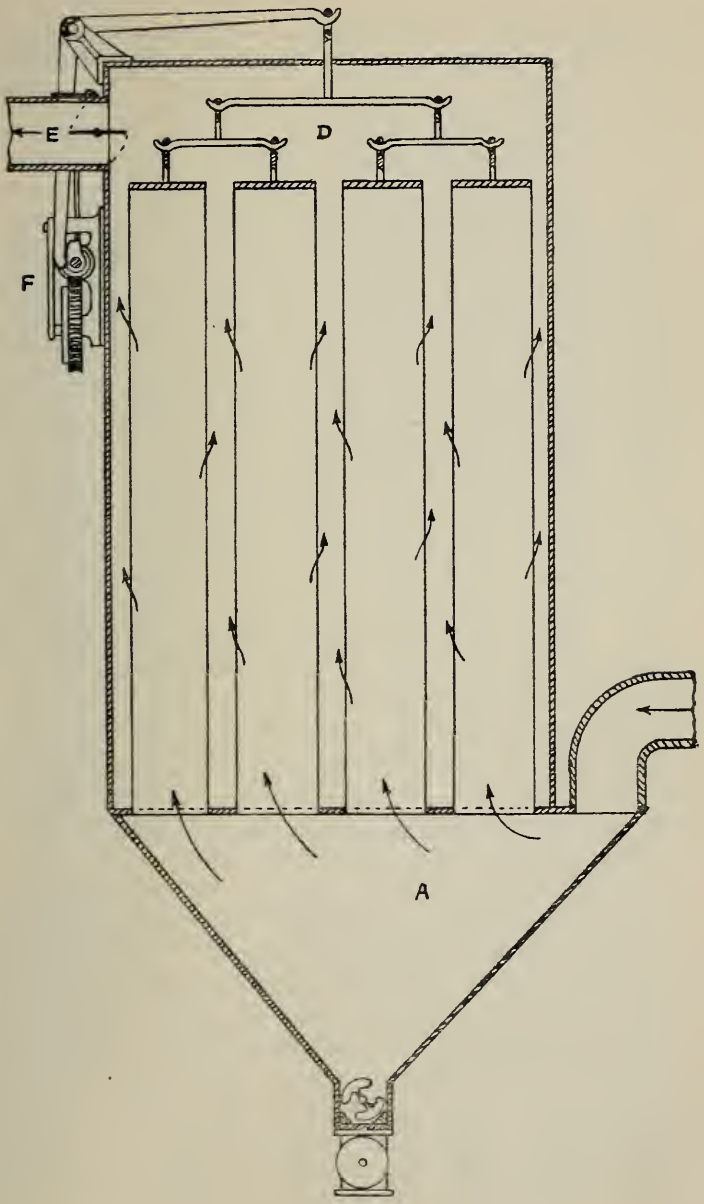


Fig. 26.
SUCTION FILTER DUST COLLECTOR.

the hopper and so through the other compartments to the fan. While this is happening the same mechanism shakes the sleeves. This shaking, combined with the reverse air current, cleans the sleeves very effectively, rendering it possible to use a fine cloth without any risk of choking.

One drawback of this machine is that when one compartment is closed the whole of the air has to be drawn through the other compartments. In a small machine containing not more than, say, three compartments, this tends to cause a perceptible irregularity in the draught, though with larger machines, when well designed, this can be almost entirely eliminated.

The suction filter is certainly the best machine that has yet been devised for cleaning dusty air in flour mills. The results are regular, the air is delivered so clean that it can be blown straight into the mill, and the interior of the machine is always below atmospheric pressure, so that if there are any leaks they are inwards, and not outwards, and no dust nuisance results.

The only objections to the machine are that if the air is to be completely clean, the back pressure is apt to be rather high, say about 2 in. water gauge, and the machine is necessarily substantially more expensive than the other types.

It is interesting to note that in Western Europe it is more and more becoming true that the only dust collectors used are the suction dust collector and the cyclone. In the United States, on the other hand, the pressure dust collector is still the commonest machine. This is no doubt partly to be accounted for by the fact that in America the milling is mostly done with relatively dry wheat, which can be dealt with more easily by pressure dust collectors than the damper wheats often used in this country, and partly by the undoubted fact

that the majority of millers in England take much more pride in having a clean and well-kept mill than do millers in the United States.

Closed Circuit Machines.

In the last chapter we dealt with the so-called "open" aspiration, in which the air is drawn through the wheat and is then cleaned and blown away into the mill or into the open air. But it has been realised for many years that there are certain advantages to be gained by a closed circuit aspiration, in which the air, after the dust has been removed, is used again and circulates round and round. The closed circuit machine occupies relatively little space and requires no trunking or separate dust collectors. On the other hand, the air tends to become charged with dust, so that it is not possible to get as effective cleaning as with an open aspiration.

In Appendix VI. we have endeavoured to work out numerically the result of aspirating wheat with air which already contains dust returned from previous aspiration. The table in the appendix shows that if the efficiency of the dust collector in the circuit is 70%, the percentage of the dust which is finally removed from the wheat, as compared with the dust removed by an open aspiration, would be 92%. Assuming that the efficiency of the dust collector could be raised to 90%, then the dust finally removed would amount to 98% ; in fact, in that case the circuit aspirator would give results practically the same as an open aspirator.

The whole question of making a satisfactory circuit aspirator hinges round the efficiency of the dust collector included in the circuit. The ideal air circuit may be taken as the ordinary

case of a set of purifiers exhausted into a suction dust collector which returns its air into the room, and so back to the purifiers.

The sole object of a closed circuit aspirator is economy either in cost or in space, and in order to achieve this the dust collector must be made smaller and therefore less efficient than it would be in an open aspiration. Most closed circuit machines, for this reason, have highly inefficient

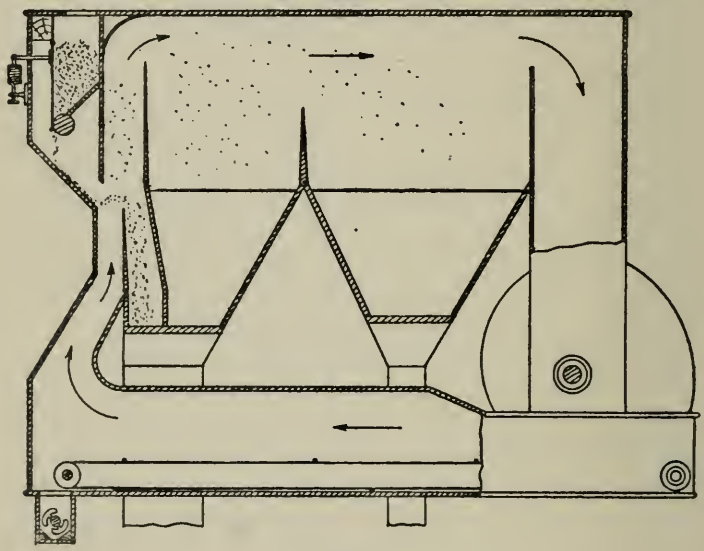


Fig. 27.
CLOSED CIRCUIT ASPIRATOR.

dust separators. For instance, in the machine shown diagrammatically in Fig. 27 the return trunk from the fan to the aspirating channel has been arranged to form a simple type of settling chamber in which the dust is deposited by gravity with some slight assistance from centrifugal force where the air current bends upwards to the aspirating chamber at the end. The efficiency of this arrangement is, of course, low.

In Fig. 28 is shown another type of circuit aspirator. The dust collecting chamber of this machine is of the cyclone type and, being of

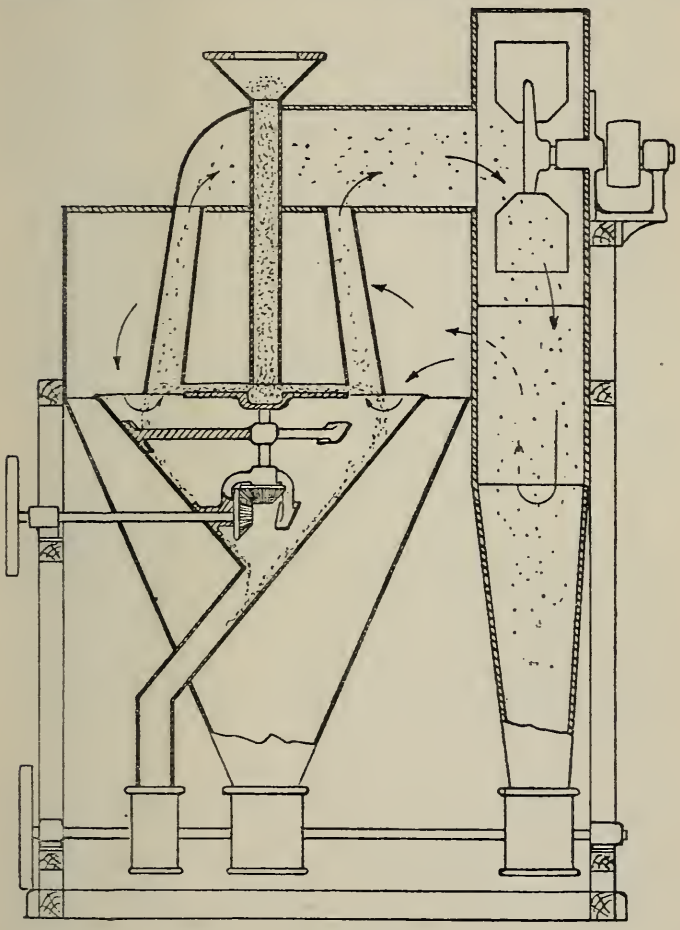


Fig. 28.
CLOSED CIRCUIT ASPIRATOR.

considerable size to deal with the required quantity of air, the aspirator proper has been made of the disc fed type and placed in the central air outlet

from the cyclone; in this way a very neat and compact machine has been produced. It must be pointed out, however, that compactness has been secured only by sacrificing efficiency. The introduction of the feed disc and wheat hopper into the central outlet of the cyclone must seriously impede, if it does not altogether prevent, the formation of the central free vortex to which the relatively high efficiency of a cyclone is due, and it is consequently doubtful whether this type of machine provides a much higher extraction of dust than the settling chamber of the previous machine. The fact is that the circuit aspirator, if it is to be cheap enough to be worth making, must include a very inefficient dust collector. It is accordingly only useful on the preliminary rough cleaning of wheat.

Semi-Circuit Aspirator.

A much more efficient machine has been devised which might be called a semi-circuit aspirator. This depends on the separating of the dust by means of a dust separating fan. A diagram of this fan is shown in Fig. 29. F is an ordinary centrifugal fan. On the same axis is mounted a revolving disc G with impellers similar to fan blades H. The dust laden air enters at K, is given a rapid rotary motion by the impellers and passes outwards round the disc and then into the eye of the main fan. At the bottom of the casing of the disc is an opening L, through which the centrifugal force, due to the high speed of the air, drives out the bulk of the dust, with about 5% of the air.

The efficiency of the air separating fan when working on wheat dust is about the same as a fairly good cyclone, varying from 80% to 90%. That is

to say, that 80% to 90% of the dust is included in the 5% of air, from which it can be almost completely removed by a smaller cyclone. Fig. 29 shows, in addition to the fan, the arrangement of a semi-circuit aspirator in which the fan is incorporated. The feed is shown at D; A is the preliminary expansion for the heavy impurities. The separated dust, with its 5% of the air, passes through a cyclone E, which delivers the light

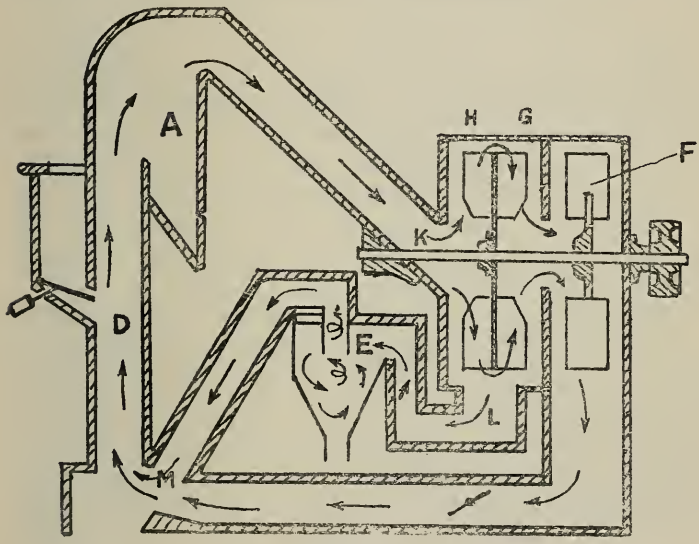


Fig. 29.
SEMI-CIRCUIT ASPIRATOR.

impurities, and then rejoins the main air current at M, and, as will be seen from the diagram, passes twice through the wheat before beginning again the same series of operations. In this case, the 5% of air is, after cleaning, returned to join the main air circuit. In other machines of the type this small proportion of air is blown away into the mill. In either case, the principle is the same; the circulating air is cleaned by the

dust separating fan which has an efficiency equal to a full sized cyclone, and therefore gives an aspiration which is almost comparable for effectiveness with an open aspiration. So far as we are aware, this is the only type of circuit aspirator in which the bulk of the dust is effectively and permanently extracted from the wheat.

Comparison of Systems.

There are several factors to be considered in deciding what type of dust collector is most suitable in any individual case. The initial cost of the installation, running and upkeep costs, value of the dust to be recovered, amount of dust that may be discharged with the air without becoming a nuisance, and space available in the mill, all influence the decision.

High efficiency is the chief point in favour of the suction filter. When dealing with fine flour dust, such as that contained in the exhaust from roller mills or flour dressing machines, only three to five parts per thousand of dust are missed, whereas a cyclone working on the same material would miss as much as 100 to 150 parts. In addition to its high efficiency the suction filter is more compact than the cyclone, and consequently cost of transport is lower and less space is occupied in the mill. It is easier to instal, requiring only trunking and a single drive, while the cyclone requires a special staging under the roof with expansion chamber and cowl outlet. This last advantage, however, is offset to some extent by the fact that the suction filter usually occupies floor space whereas the cyclone, placed under the roof, is clear of all floors and leaves more space available for other machinery.

On the other hand the cyclone has a far lower initial cost, being about one third only of the suction filter. Its running costs are limited to the power absorbed by its back pressure on the fan which is only $\frac{1}{2}$ in. to 1 in. water column against 2 in. to $2\frac{1}{2}$ in. for the suction filter, which also requires power for the drive to the collecting worm and shaking gear. Once installed the cyclone has no upkeep cost whereas the filter requires, from time to time, new sleeves and replacement of the moving parts of the shaking gear. Finally the back pressure of the cyclone is constant while that of the suction filter varies each time a set of sleeves is cleaned. Summarising, the filter's advantages are efficiency and compactness, the cyclone's initial cheapness, simplicity of working and low running costs.

The " Multicone " dust collector, if satisfactorily developed, will possess some of the advantages of both filter and cyclone. Its efficiency will compare with that of the filter, probably 5 to 10 parts per thousand of roller mill dust being missed. Its initial cost will be less than that of the filter but greater than that of the cyclone ; its running cost about that of the filter; there will be practically no upkeep costs.

There is no hard and fast rule that determines which type of collector is most suitable at any particular point in the mill. Much depends on the types of machines being exhausted and on the other factors previously mentioned. It is possible, however, to generalise to a certain extent. Under conditions existing in most mills cyclones are used principally where the value of the dust recovered is small, as, for example, with the wheat intake plant and wheat cleaning machines, especially with those fitted with their own fans.

They are used exclusively for conditioning plant where the wet, sticky "beeswing" would soon clog the sleeves of a filter and render them useless. In the mill proper they are found quite serviceable on the exhaust of purifiers especially those working on the coarser stocks, but owing both to the fineness of the particles and to the relatively high value of the dust, filters are preferable on the roller mill, plansifter and centrifugal exhausts.

Chapter V.

CONDITIONING—SCIENTIFIC DATA.

Before proceeding to deal with the actual process of conditioning, it will be useful to consider the technical terms used in describing it and the facts on which it is based, and to give the main scientific data necessary for designing and working a conditioner.

Moisture.

Diffusion.—Like heat, water vapour tends to diffuse or spread itself more or less evenly wherever it is present. The rate of diffusion differs widely with the nature of the substance in which the moisture is held and with its temperature. Generally, the higher the temperature, the more rapid is diffusion.

Absorption is the transference of moisture from one substance to another. We use this term when we think of a substance *receiving* moisture. When we think of a substance giving it up, we speak of "drying."

Drying or reducing the moisture held by any substance can be done in two ways :—

(*a*) By mechanical separation, as in a whizzer or centrifugal dryer, and

(*b*) By evaporation, which is really the transference of moisture from the substance to be dried to some other substance, frequently the atmosphere.

The rates of both absorption and drying are limited by the rate of diffusion which, in the

case of wheat, is rather slow. Very little is known scientifically of the rate of diffusion of moisture in the wheat berry. From practical experience it is known to differ considerably in different varieties of wheat, certain wheats having a slower rate of diffusion than others.

Dedrick* points out that the rate of absorption of water vapour by wheat increases after it has been stored in a damp state for some hours, and he explains this as the result of biological change in the wheat.

Graham† has shown that the rate of diffusion of water vapour in any substance increases with an increase of temperature and this is the principal reason for heat treatment. That is to say, the use of heat speeds up diffusion and enables either absorption or drying to be carried out in less time than would be required at ordinary atmospheric temperatures.

Absorption.

In an attempt to throw more light on the question of absorption of moisture by wheat, a series of laboratory experiments was undertaken. A quantity of Manitoba wheat, containing 13.8 % moisture, was washed and whizzed and then heated in a closed vessel to a given temperature, the supply of heat being regulated so as to raise the wheat to the required temperature in twenty minutes. In the various experiments the moisture content at this stage was found to vary from 18.5 % to 19 %. A sample of the wheat was then subjected to an aspiration with air at the same temperature as the wheat, and it was found that when the surface moisture had been removed the moisture content of the wheat was reduced in all cases to 18 %.

The washed and whizzed wheat, with a moisture

*"Practical Milling," by B. W. Dedrick—p. 84. First Edition.
†The diffusion rate of gases is inversely as the square root of their density. "Law of Diffusion of Gases," by T. Graham.

content of from 18.5 % to 19 %, was then maintained at the desired temperature in the closed vessel. The temperatures selected were 60°F., 100°F. and 130°F. At intervals of a quarter of an hour, samples were withdrawn, aspirated so as to remove all surface moisture, and tested for internal moisture. The results are shown in Table I. and graphically in Fig. 30. It will be noted that there was a varying amount of surface moisture in the different experiments, but it is thought that this does not affect the rate of absorption; this is indicated by the fact that the points in Fig. 30 lie very nearly on straight lines.

It will be seen from the curves that to increase the amount of moisture by $\frac{1}{2}$ % took 90 minutes at 60°F., 36 minutes at 100°F., and 30 minutes at 130°F.

In such an experiment fairly large errors in individual results are unavoidable, but the curves show quite clearly the increased rate of absorption as the temperature increased. These results are, of course, of relative value only. As is well known the rate of absorption varies enormously with the initial dryness of the wheat, the quantity of moisture present and the nature of the wheat itself. For instance, it has been found that Indian wheat containing 10 % moisture may have its moisture content increased to 18 % by washing, whizzing and conditioning for some 40 minutes at a temperature of about 100°F. Nevertheless the figures obtained, if considered relatively, do show that the time required for the absorption of moisture by wheat is reduced by increasing the temperature to which it is subjected.

The necessity for much further work on this important subject will be evident.

Table I.

Absorption of Moisture by Wheat at Different Temperatures.

Percentage increase in absorbed moisture content.

Moisture Content, Original ... 13.8 %

Moisture Content after washing, whizzing and aspirating ... 18.0 %

Time Heated Hours.	Temp. 60°F. Initial Surface Moisture .8%	Temp. 100°F. Initial Surface Moisture 1%	Temp. 130°F. Initial Surface Moisture .5%
0	0	0	0
0.25	0.1	0.3	0.2
0.5	0.2	0.2	0.5
0.75	0.3	0.7	—
1.0	0.3	0.8	—
1.25	0.4	1.0	—
1.5	0.5	—	—
Rate of Absorption %per hr.	0.32	0.80	0.95

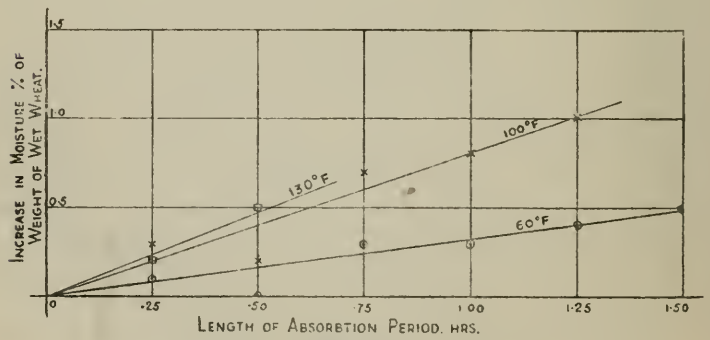


Fig. 30.
Graph Showing Ratio of Absorption.

Drying.

When we come to consider drying, we are on somewhat firmer ground. The moisture carried by wheat is often divided into *Surface Moisture* and *Internal Moisture.*

Surface moisture exists usually in the form of a fine film or small globules of water on the rough surface of the wheat berry. As is shown in Appendix VII., much of such moisture can be driven off by efficient whizzing and aspiration. If it is evaporated the rate of evaporation is not dependent on the rate of diffusion of moisture through the berry and can, consequently, be much more rapid than in the case of moisture which has been absorbed.

Natural Moisture is a term used when referring to the moisture content of wheat which has not been treated, and it is often assumed that it is more difficult to remove natural than added moisture. Innumerable laboratory experiments, however, have shown that, from a drying point of view, there is no difference between the natural or original moisture of wheat and moisture which has been added and re-absorbed after drying.

Temperature.

Whether the moisture to be evaporated is on the surface or is held between the cells of the substance to be dried, the temperature at which drying takes place is an all important factor. The curves, Fig. 31, illustrate this. They show the rates of drying of wheat maintained at constant temperatures whilst hot air is blown through it. It will be seen that when the drying temperature is 112°F. the moisture in the wheat falls from 19·2% to 16% in twenty minutes, whereas, if the drying

temperature is only 92°F. it takes twice as long—forty minutes—to effect the same amount of drying. *It is evident then that the higher the temperature at which drying takes place, the more quickly can it be performed.*

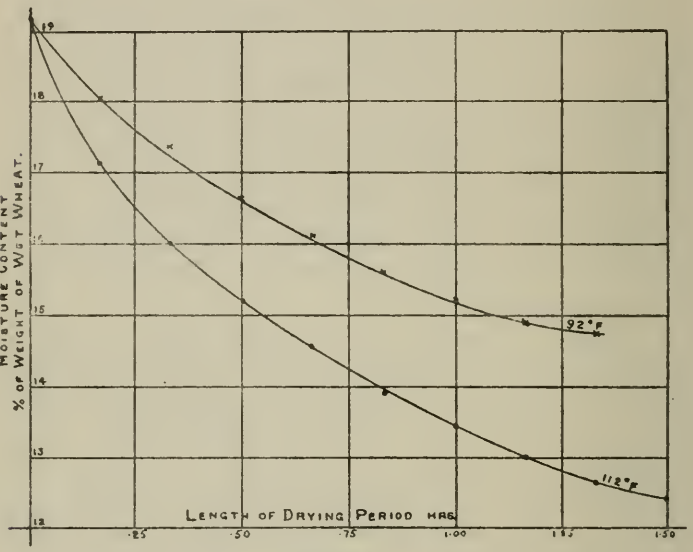


Fig. 31.
DRYING CURVES.

In both the problems of getting moisture into wheat—absorption—and in getting it out—drying—the higher the temperature the quicker it is possible to perform the operation. For this reason designers of conditioners are always tempted to work with high temperatures, but they are at once faced with the fact that at a certain point there is grave risk of causing damage to the wheat. From work done by Kent-Jones* it is seen that this danger point depends on (a) the moisture content of the wheat; and (b) the length of time the temperature is maintained. He has shown

* "Modern Cereal Chemistry" Chapter X. 1927 Edition

that even very prolonged heating at 120°F has no effect on the strength of dry wheat, but for ordinary conditioner work, where moist wheats are dealt with, this temperature should never be exceeded, and generally 110°F.—115°F. has been accepted as the maximum safe temperature in conditioning practice where it is not desired definitely to break down the gluten. At these temperatures it is possible quickly to evaporate all moisture lying on or near the surface of the wheat berry, and if the surface is kept dry, by passing a current of dry air over it, the moisture in the interior tending to diffuse equally throughout will, in time, be reduced also. But at such temperatures the time required for this diffusion is still considerable.

One disadvantage of rapid surface drying arises from the fact that wherever evaporation takes place much heat is used up, and if this heat is not supplied from an external source it is extracted from the substance being dried. This means a lowering of its temperature and a corresponding reduction in the rate of diffusion, and, consequently, of the rate of removal of internal moisture.

Air.

Air is employed as a means of carrying away moisture vaporised by heat in all wheat drying operations, except those which work at pressures well below that of the atmosphere, viz. " vacuum " dryers. Sometimes it is used in the dual capacity of a conveyor of heat to the grain and a transporter of moisture from it. The moisture holding capacity of air rises very rapidly with its temperature; one thousand cubic feet of air at 50°F. can carry only half a pound of water vapour; at 110°F. the same quantity of air can carry 3·6 lbs. or about

seven times as much. But air has a very low heat carrying capacity. Its specific heat is ·238, which means that the heat required to raise one thousand cubic feet of air one degree in temperature or given up by it in falling one degree, is only some eighteen B.Th.U.* at ordinary temperatures.

It follows that whilst the use of air as a means of carrying away moisture can be very efficient, especially at the higher temperatures, its use as a means of conveying heat to effect evaporation involves moving large volumes very much in excess of those required to carry away the moisture set free. In an ordinary hot air dryer, where air is used to convey heat to the grain as well as to carry away evaporated moisture, the large volume of air used and the affinity of air for moisture result in the rapid removal of such moisture as is readily available for evaporation, *e.g.* surface moisture. The heat absorbed by this evaporation is furnished by the air from its slender store at the cost of a big fall in temperature. The general effect is that the temperature at which evaporation takes place is low, much below that of the entering air, and the grain is never raised to a temperature sufficiently high to permit of the easy passage of moisture from the inside to the surface of the berry; the air leaves the grain at a comparatively low temperature, generally carrying with it much less moisture than it is capable of holding.

The importance of high temperatures in the exhaust air from any drying operation is shown by the composite graph, Fig. 32, where the ordinary air saturation curve, expressed as lbs. of water per thousand cubic feet of air, is shown on the left, whilst on the right is shown another curve, giving the units of heat carried by the air, on the same temperature base. From these curves it will be

*The British Thermal Unit (B.Th.U.) is the quantity of heat required to raise 1lb. of water by 1°F. when at its maximum density, *i.e.*, from 39.1°F. to 40.1°F

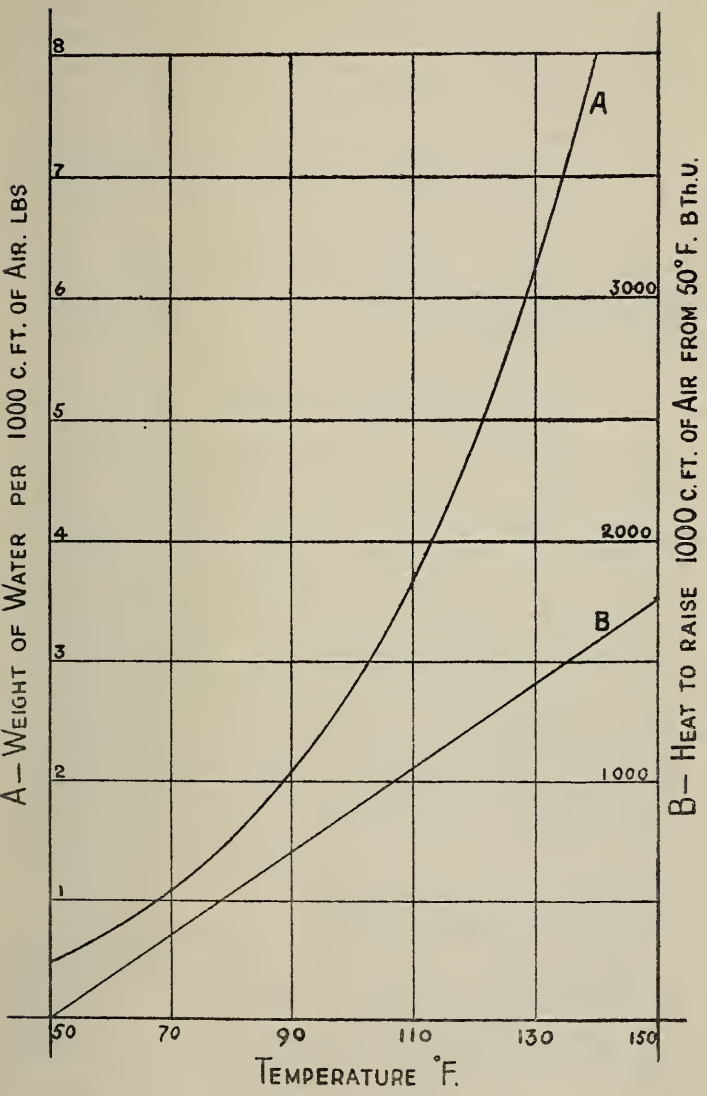


Fig. 32.
Saturation and Heat Curves.

seen that with saturated air entering a dryer at 50°F. and leaving it at 90°F., again saturated, 1.5 lbs. of water* is picked up by every thousand cubic feet and the amount of heat carried away is 720 B.Th.U.

If, however, the escaping temperature is raised to 110°F. the weight of water carried away is 3.2 lbs. or rather more than double, whilst the heat required to raise the temperature of the air is 1075 B.Th.U., an increase of only 50%. With higher discharge temperatures the advantage is still more marked.

Heat Used and Lost.

Every pound of water evaporated requires roughly one thousand B.Th.U. of heat. There is no reduction possible in the amount of heat required to effect vaporisation; this must be supplied before water can be turned into vapour no matter what the temperature. It varies slightly with the temperature but, inside the range we have to consider, the variations are so small as to be negligible. The *rate* at which evaporation takes place rises rapidly with a rise in temperature, but the *quantity of heat* required remains the same. The amount of heat which does vary with the temperature is the amount which must be allowed to escape to the atmosphere with the air used for carrying away the moisture.

Under the most favourable conditions the heat so carried away will be at least 300 B.Th.U. for every pound of water evaporated. To reduce this loss to a minimum it is necessary to ensure, not only, as shown above, that the air should escape at the highest practicable temperature, but that it should carry with it as nearly as possible its full complement of moisture, in other words,

*Saturated air at 50°F contains .5 lbs. moisture per 1000 cub. ft.
" " " 90°F. " 2.0 " " " " " "
" " " 110°F. " 3.7 " " " " " "

should be nearly fully saturated. To secure both the desirable high air temperature and high saturation, it is necessary that the air be in contact with the wheat for a sufficiently long time to allow of its picking up both heat and moisture and that by one means or another the wheat be maintained at the highest safe temperature.

Heating Surface.

As will be shown in the next chapter, a common device for heating wheat is the cast iron radiator in which hot water is circulated. Careful measurements of the amount of heat transmitted by a good type of radiator have shown that under ordinary working conditions, viz. with wheat entering the machine at 60°F. and being raised to 110°F. and with water fed at 200°F., each square foot of radiator surface will transmit, on an average, 600 B.Th.U. per hour. The rate of transmission of heat, depending on the temperature difference, is naturally higher at the commencement and lower as the wheat is raised in temperature, but the figure given is about the average for the range specified. If steam at 212°F. is employed in place of water at 200°F. the heat transmitted amounts to over 720 B.Th.U. per square foot per hour.

In designing a heater or a dryer it is important to ensure that the heating surface is sufficient to transmit the heat required. If we take the specific heat of wheat at ·5, it is evident that if the wheat is raised from 60°F. to 110°F. and water is used as the heating medium, we require :—

$$\frac{(110—60) \times \cdot 5}{600} = \cdot 041 \text{ sq. ft. heating surface per pound of wheat.}$$

Similarly, for the evaporation of water, requiring, as we have seen, 1,000 B.Th.U. plus, say, 300 B.Th.U. carried away by the air, we need :—

$\frac{1300}{600} = 2{\cdot}17$ sq. ft. heating surface per pound of water evaporated.

Cooling.

The cooling of wheat follows the same laws as the heating of it. The heat to be got rid of must be transferred to another substance and the most convenient substances are water vapour and air. As every pound of water turned into vapour absorbs about one thousand heat units, it follows that if one pound of water is evaporated from one hundred pounds of wheat and there is no other source of heat, the wheat will give up one thousand heat units. For one hundred pounds of wheat to do this there must be a drop in its temperature of approximately 20°F. since the specific heat of wheat is roughly ·5. In other words, every 1% moisture evaporated in cooling wheat means a fall in temperature of 20°F. in addition to any fall caused by the loss of heat carried away by air.

But it should be noted that a fall in temperature does not necessarily mean that evaporation is taking place. If there is little surface moisture on the grain and large quantities of cold air are passed through it, the temperature will be reduced, not by evaporation, but by actual contact with the cold air, and diffusion of the moisture inside the berry will be slowed down. In other words, rapid cooling tends to retain moisture in the interior of the berry whilst making its surface comparatively dry. In many cases this is what the miller aims at but in all cases where

it is desired to effect the maximum amount of drying, the rate of cooling should be such that the internal moisture has time to find its way to the surface and there effect cooling by evaporation.

Summary.

The rates at which moisture can be driven into or dried out of wheat depend on the rate at which it diffuses in the wheat berry.

The Rate of Diffusion differs for various grains but it always increases rapidly with increased temperature. There is, however, a limit to the temperature which can be used with safety. Time, therefore, is an important factor in both absorption and drying.

Drying should not be allowed to proceed at a greater rate than that at which internal moisture can find its way to the surface.

Air is usefully employed as a means of conveying away vaporised moisture. Its moisture holding capacity rises rapidly with its temperature. As a means of conveying heat to the grain it is inefficient owing to its small heat carrying capacity. It is important that air used for conveying away moisture be discharged at the highest possible temperature and as nearly as possible saturated.

Heat. The quantity of heat necessary to evaporate one pound of moisture is fixed and is the same for "internal" as for "external" moisture. The *time* required to evaporate internal moisture may be greater but the quantity of heat required is the same.

Heating Surface. In conditioners of the radiator type, the heating surface required to raise one hundred pounds of wheat per hour from 60°F. to 110°F. is found to be 4·1 square feet. To evaporate one pound of water per hour about 2·2 square feet heating surface are required.

Cooling. Cooling must be done slowly if the maximum evaporation is required.

Chapter VI.

CONDITIONING—THE PRACTICAL PROBLEM.

It is often said that the first step in dealing with any question scientifically is to get a clear statement of the problem. Such a statement is a big step on the way to a solution.

The first thing we have to consider then is—what exactly do we mean by conditioning?

Our definition, which follows closely that adopted by Humphries, is as follows :—

Wheat conditioning is the process of preparing wheat for the mill in such a way as to facilitate the best separation of the bran from the endosperm, and, as far as possible, to improve the baking value of the resultant flour.

The first object in any conditioning process is to get the wheat to the first break of the mill in a certain physical state. This depends mainly on the percentage and distribution of moisture in the wheat. It has already been shown in the preceding chapter that the use of heat facilitates and hastens the distribution of moisture and thus enables the wheat to be brought into the required physical state in much less time than would be required if no heat were supplied.

We propose to use the word " tempering " to describe this purely physical treatment of the wheat, with which we deal in the present chapter.

The other aspect of wheat conditioning is the effect of heat treatment on the strength of the

wheat. This is a matter of the greatest interest and importance to millers, but it is in no sense an engineering problem ; it is a problem rather to be studied by the chemist and the biologist in conjunction with the practical miller. In spite of the interest and importance of this problem we therefore refrain from dealing with it in this book. We propose to confine ourselves to the physical side of the conditioning problem.

Tempering.

In tempering his wheat the miller has in view two objects, (1) to improve the process of milling, (2) to secure the right percentages of moisture in the finished products. Each of these objects contains various sub-divisions. As regards the first object, the proper tempering on the first break has four direct results :—

(1) To toughen the bran and so prevent bran powder being formed.

(2) To secure the easiest separation of the bran from the endosperm.

(3) To render easy the subsequent breaking down of the endosperm.

(4) To get accurate and easy sifting on the dressing machines.

Four very important indirect results follow.

The toughening of the bran leads to a better separation of the bran from the endosperm, cleaner break flours, and better colour in the flour right through the mill. This is undoubtedly the most important result of tempering.

The second result is a reduction of the power required by the roller mills, and this in its turn causes :—

The third result, which is less heating and therefore less loss of moisture by evaporation.

The fourth result of good tempering is due to the fact that just as the wheat must be soft enough for easy grinding, so it must be hard enough for easy sifting. If any portion of the mixture is seriously damp, sifting becomes difficult, and the capacity of the mill is immediately reduced or, to put it in another way, good tempering means increased milling capacity.

The second object is to secure the right amount of moisture in the finished products, that is, in each grade of flour and offal produced. As Humphries said many years ago, moisture is one of the best flour improvers. There are few things more important for a miller than to get this moisture percentage exactly right.

This is secured mainly by the original tempering of the wheat, that is, by the amount and distribution of moisture in the wheat as it comes to the first break. But there are so many different objects which the miller is trying to achieve that the tempering which is right for the purposes of the first breaking down and sifting of the wheat, may be quite wrong for the purpose of securing the right moisture in the finished products. Clearly all these different objects are not likely to be achieved by the simple process of tempering the wheat. There are, however, certain methods by which the difficulty, as regards the moisture of the finished products, can be overcome, so reducing the multiplicity of objects of the tempering problem.

Generally, in this country, it is found that wheat tempered for the best working throughout the mill gives products which tend to be drier than is desirable. This is mainly, if not entirely, due to evaporation during the milling process. Two

means have been suggested for dealing with this. The first is to prevent evaporation either by cooling the wheat before the first break or by artificially damping the atmosphere throughout the mill. The second is to allow evaporation to take place, but by means of sprays, to replace such portion as may be desired of the water lost by evaporation in the flour and offals. This is, of course, the Humphries process. These methods may be looked on as legitimate extensions of the tempering process. They are in the right direction but they are delicate processes, requiring scientific control. It is not proposed to deal with them here.

The practical problem of tempering is how to arrive most quickly and most cheaply, and in the most convenient and reliable way at the desired quantity and distribution of moisture in the wheat berry. Washing is nowadays regarded as essential in this country so that here we have always to start with wheat which has been washed and whizzed, and has generally, an excess of surface moisture. In the case of wheats whose internal moisture is already high, most of this surface moisture has to be got rid of. In cases where the internal moisture is too low to permit of satisfactory milling it is desirable to convert some or all of this surface moisture into internal moisture.

Cold Treatment. The old-fashioned way of dealing with this problem was by simply mixing the wheats which were too moist with those which were too dry and so getting a happy medium. Where one happens to have the right proportions of dry and damp wheats this is a convenient and simple process, but the real objections to it are that one cannot rely on having the right wheats available, and that, even when one has the

process is an inconvenient one, large and expensive storage capacity is needed, and days are required to do the work which can be done in an hour in a modern conditioner.

Heat Treatment. The modern conditioner aims at doing the same work, by the use of heat, in much less time, at less cost, and in a way which can be controlled with much greater ease. The wheat with which it has to deal may be classified as :—

(1) wheat with too much internal moisture,

(2) wheat with too little internal moisture.

Wheat which has too much internal moisture. In this case all the excess surface moisture must first be removed. It is stated in the preceding chapter that much of this surface moisture exists as a fine film or small globules of water adhering to the rough surface of the berry. Most of such moisture can be got rid of as water by good whizzing followed by a really effective aspiration by cold air,* and this is by far the cheapest way to get rid of it. What remains must be evaporated as must the excess moisture from the interior of the berry. This excess moisture must be brought to the surface of the berry, where alone evaporation can take place.

For the removal of internal moisture in the most efficient way a consideration of the data dealt with in the previous chapter shows us that three things should be aimed at :—

(1) The drying must be done at the highest safe temperature and this temperature should be maintained throughout the whole drying process.

(2) The rate of evaporation from the surface should not greatly exceed the rate of diffusion of the moisture from the inside.

*See Appendix VII

In other words 'time' is necessary to effect drying.

(3) When air is used to convey away the moisture it should leave the wheat at the highest possible temperature and as nearly as possible saturated. In this way the quantity of air required and the loss of heat carried away by it are reduced.

Wheat which has too little internal moisture. Here the problem is that of driving in moisture from the surface to the interior of the berry. It is comparatively easy to add any required quantity of surface moisture which would, in time, diffuse itself evenly throughout, but by the application of heat this process can be hastened. Here again, however, there are limits to the extent to which the comparatively low temperatures permissible can speed up the process. Time must be allowed for the moisture to permeate the grain.

At present the only reliable guide as to the time required is practical experience. The figures Table I, and the curve Fig. 30, in the preceding chapter give a rough indication of the time required under certain conditions in the case of one particular wheat. The practical tests referred to in the same chapter show that under mill conditions a considerably higher rate of diffusion was obtained. Until much more work has been done on this subject, the only thing of which we can be quite sure is that the higher the temperature the more rapidly is moisture absorbed, and this justifies the common practice of subjecting wheat which has too little internal moisture to the highest safe temperature, without air circulation, in order to hasten the diffusion of moisture throughout the berry.

Owing to the slow rate of diffusion, there must be, at any given moment when moisture is being

driven in, an excess of moisture on or near the surface, and when the desired interior moisture content has been attained this excess moisture must be evaporated. In common conditioner practice this is done by passing a current of cold air through the grain. This serves the double purpose of removing excess external moisture and cooling the stock to a temperature at which it is safe to pass it to bins.

It will be evident from the above that in order to get quick and uniform diffusion of moisture in the grain, whether for purposes of evaporation or absorption, there must be quick and uniform heating of the grain to the maximum safe temperature. This temperature must be maintained for a sufficient time to allow the moisture to find its way out or in, and, only after the process is complete, should the grain be cooled and any excess surface moisture removed.

Methods Employed.

Two principal methods are used in raising the temperature of grain :—

(1) Blowing hot air through the grain.

(2) Bringing the grain into contact with heated surfaces.

Hot Air. The old dryer leg, a typical example of the hot air method, is shown in section in Fig. 33. In this the air was heated to a temperature of about 160°F. by being passed through a steam coil heater and then blown through a thin stream of wheat from which it sucked up all the moisture it could in the short time it was in contact with the grain. It then escaped to atmosphere carrying with it a great deal of heat and some moisture. The working tempera-

ture attained was never high because the evaporation taking place absorbed most of the heat the air could give up in the short time it was in

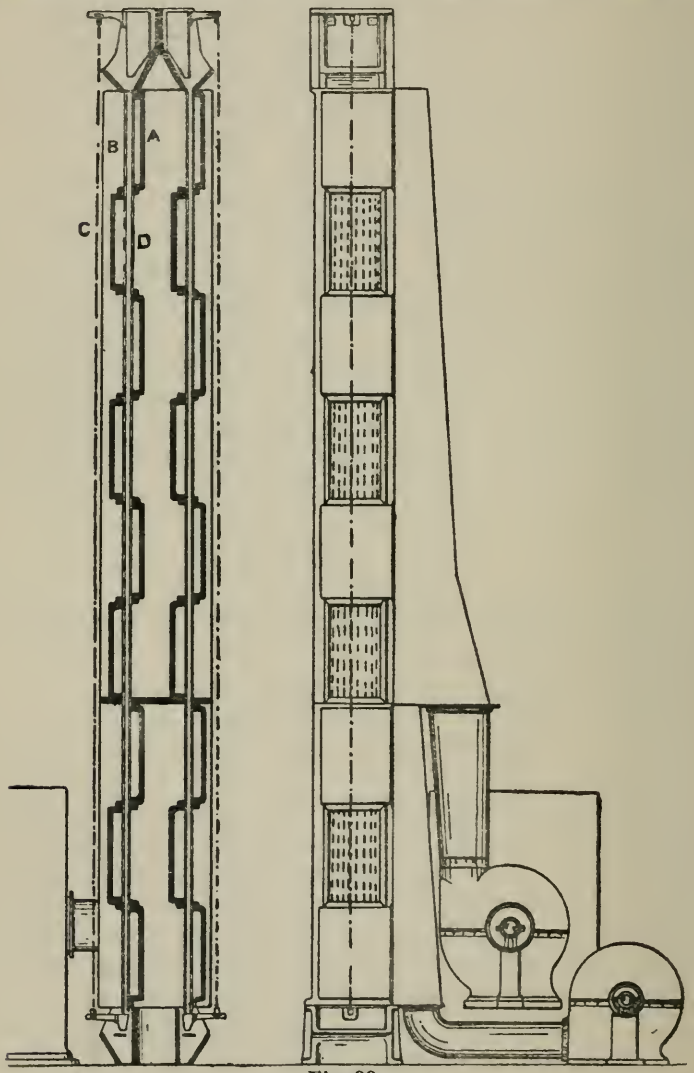


Fig. 33.
DRYER LEG.

contact with the wheat, and there was very little available for raising the temperature of the wheat itself. For this reason the dryer leg, although fairly efficient when used for evaporating surface moisture, was very inefficient in drying out internal moisture. Although now little used in this country the principle of the dryer leg, variously applied, is still employed by American makers of dryers. An American dryer was recently tested under the most favourable conditions possible, when evaporating 1·81% moisture from wheat, and it was found that for every pound of water evaporated from the grain 2·75 lbs. of steam were condensed in the air heater.

Hot Air Closed Circuit. Recently an important modification of the hot air method has been introduced in which a preliminary heating of the grain is effected by means of air moving in a closed circuit. Air from a fan is passed over a heater and through the grain but instead of escaping to atmosphere it is led back to the fan and so round again. In such a circuit the air soon becomes saturated, no evaporation takes place and as long as no air escapes to atmosphere there is no heat loss other than the inevitable loss due to radiation.

When it is desired to effect drying, a portion of the moisture laden air as it leaves the grain is allowed to escape to atmosphere and fresh air is drawn in to the system by the fan. By careful regulation of the quantity of air passed to atmosphere and replaced by fresh cold air the amount of evaporation can be controlled to some extent. A diagram of a machine of this type is shown in Fig. 34. Owing to the low heat carrying capacity of air, this method involves circulating great volumes of air through the wheat in order to raise its temperature. This necessitates large

air trunks and consequently considerable loss of heat by radiation.

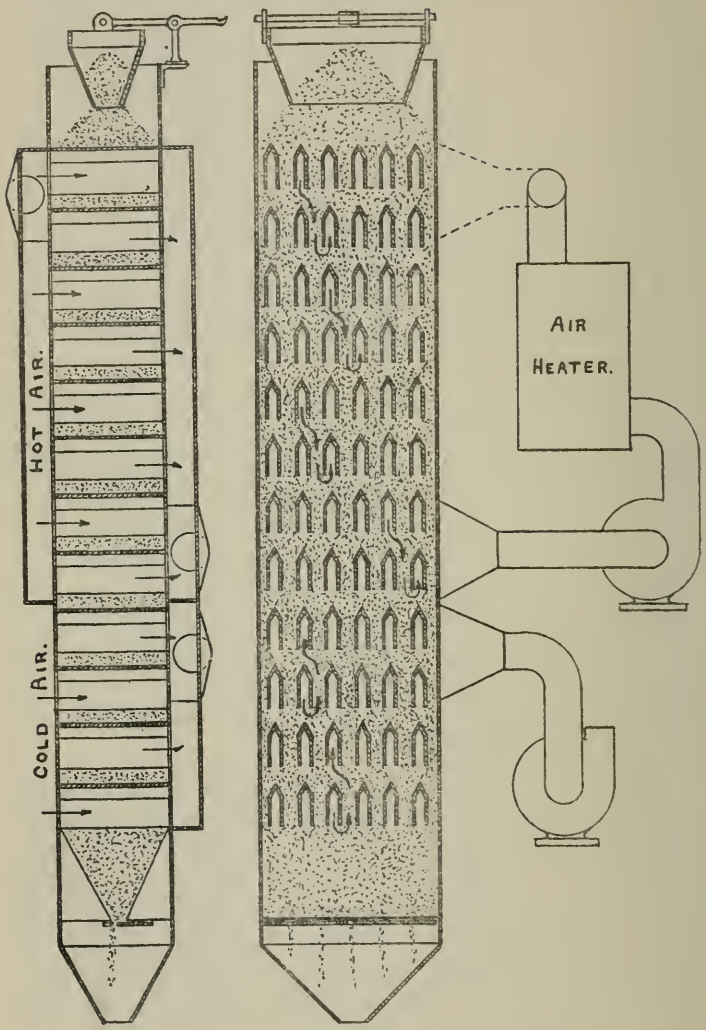


Fig. 34.
PART-CLOSED CIRCUIT CONDITIONER.

With the circuit closed, the air may leave the heater at, say, 190°F. carrying only a part of the

moisture which at that temperature it is able to hold. On coming into contact with comparatively cold grain, it rapidly absorbs moisture and gives up heat and by the time it has traversed the depth of wheat through which it has to pass, its temperature has fallen to that of the wheat, and with it its moisture holding capacity so that it has to give up some of the moisture it absorbed on entering. The net result is that the wheat, as it passes from one set of ducts to another, is subjected to alternate drying and damping treatment, and considerable variations in temperature.

The air leaves the grain fully saturated and any further loss of heat, *e.g.* by radiation from the air trunks, must result in moisture being deposited in the trunk. On re-heating, the moisture holding capacity of the air is again increased and the same cycle is gone through.

The moisture deposited in the air trunks is, of course, extracted from the wheat, and where drying is not required it becomes necessary to replace it, for which purpose a jet is fitted to blow steam into the air as it leaves the heater. There are other disadvantages arising from the difficulty of keeping the air in the system free from beeswing and other similar impurities. These tend to coat the tubes of the air heater and reduce its heating capacity.

When appreciable drying is necessary, hot moisture-laden air is allowed to escape to atmosphere and is replaced by cold air drawn into the system and passed over the heater and the principle approaches that of the hot air dryer. The difference is that by careful regulation of the amount of air escaping to atmosphere it is possible to ensure that it is nearly saturated.

Under these circumstances one would expect the efficiency to be somewhat higher than that of the

ordinary air dryer and some results obtained show that although this is the case the efficiency of the closed air circuit machine is still well below that obtainable in a machine of the radiator type. Results of these tests are set out in Appendix VIII. On examination of the results it will be noted that the original moisture content and the evaporation effected vary in every case. This makes an exact comparison impossible since, as in the case of the part closed circuit machine, drying from 21·35% to 19·6% is less difficult than drying from 18·5% to 16·69%, or from 19·9% to 17%. When allowance is made for this, the tests show that of the three types the radiator machine has much the highest efficiency.

Heated Surfaces or Radiators. These have been used in several forms for a number of years for raising the temperature of wheat by contact. Both steam and water are employed to convey heat to the surfaces. Steam at once appeals to the designer as the more convenient and economical. It carries a large quantity of heat per lb., flows easily and gives up its heat readily. But when temperatures below about 200°F. are required regulation so as to secure a uniform temperature over a large surface is extremely difficult. For this reason water is generally preferred. Its temperature can be easily regulated and with reasonable care in design a uniform distribution of heat over a large surface can be secured.

Form of Radiators. Various forms of radiators have been employed or suggested. One, the Kennedy Wheat Heater, consists of a number of steam heated tubes contained in a cylinder which also holds the grain to be heated. As the cylinder revolves slowly it lifts up the grain and allows it to fall over the heated tubes. In another form, which at first sight differs radically but is really a

surface heater all the same, the grain is passed slowly down inside a number of relatively small tubes which are encased in a shell containing steam or hot water. But by far the most common type of radiator used in this country is an adaptation of the type used for heating buildings. The arrangement of a machine fitted with such radiators is shown in Fig. 35. Machines of this type have been generally adopted in this country because :—

(1) The heat supply and air supply being independent, the wheat can be raised to the required temperature without loss of moisture or the loss of heat due to evaporation.

(2) Evaporation of all moisture can be carried out at

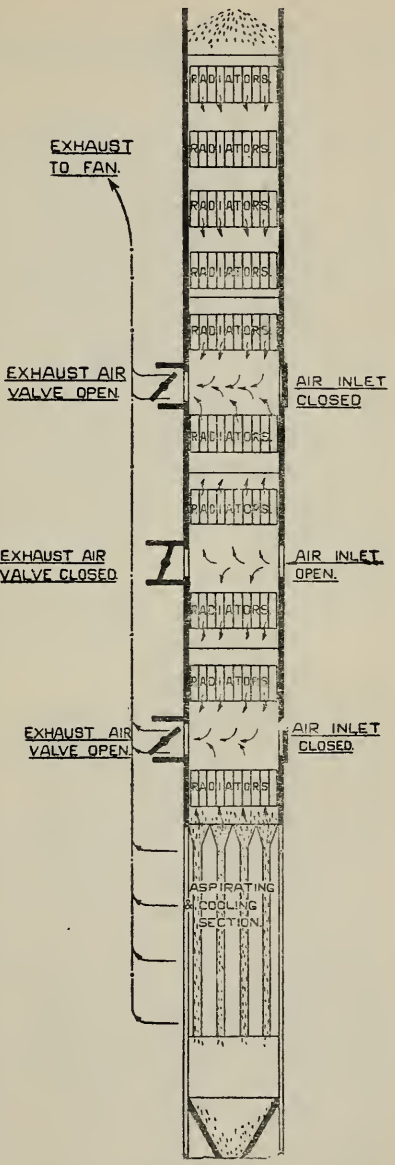


Fig. 35.
RADIATOR CONDITIONER.

a high temperature and, therefore, more efficiently than in a machine of the hot air type.

(3) Moisture can be driven into the interior of the berry by heating the wheat and allowing time for the moisture to diffuse.

(4) Moisture can be dried out from the interior by first heating the wheat and then applying just sufficient air to remove the moisture from the surface as it diffuses from the interior.

(5) The loss of heat carried away by the air is minimised by the high temperature and high degree of saturation of the air discharge.

Whatever the type of radiator used three things are essential if it is to perform its function efficiently :—

(*a*) It must have *sufficient heating surface* to convey the required amount of heat to the wheat.

(*b*) The heating surface must be *uniformly distributed* throughout the mass of wheat to be heated.

(*c*) There must be an *efficient flow* of the heating medium whether steam or water to maintain the whole of the surface of the radiator at the required temperature.

Heating Surface. We have seen in the previous chapter, that for cast iron radiators of good design heated with water at 200°F. ·041 square feet heating surface is required for every lb. of wheat to be raised from 60°F. to 110°F., and 2·17 square feet for every lb. of water to be evaporated. If steam at one lb. pressure is used in place of water the amount of surface required is reduced by about 17%.

Uniform Distribution. Unless the heating surface is evenly distributed throughout the wheat it will not give up its heat uniformly nor will the wheat be uniformly heated. It is impossible to ensure that every grain will come in contact with the heating surfaces of the radiator and remain in contact for the same time as every other grain. Heat passes through grain itself only very slowly and an absolutely uniform heating is almost impossible of attainment. Attempts to secure uniformity of heating by mixing the grain, as it leaves one portion of the heater before entering another, have been many and various. None has succeeded in getting perfect regularity of heating. A recently introduced type of radiator sets out to solve the problem by dividing the wheat into very thin streams of equal thickness so that no berry in any stream is more than three-quarters of an inch from a hot surface. In this way practical uniformity appears to be attained.

Efficient Flow. If, for any reason, the flow of water or steam to a radiator is insufficient to maintain the temperature of its surface there will be a drop in the amount of heat transmitted and a lack of uniformity in its distribution. Where water is employed and the circulation is on the thermo-syphon principle, viz. dependent on the difference in density of columns of hot and cold water, the pipe connections between radiators and water heater must be carefully designed to ensure that a sufficient flow of water is available throughout the whole system. A common cause of trouble in this connection is the existence of air locks either in the radiators themselves or the pipes leading to them.

Flow of Grain. With a perfectly uniformly heated system of radiators arranged in the best

possible way it is still impossible to heat up equally a moving mass of wheat unless the movement of the wheat is uniform. If one portion is moving over the radiators faster than another the fast moving grain will pick up less heat than the slow moving grain. It is, therefore, of prime importance that there should be a uniform grain flow. This can only be attained by arranging :—

(*a*) That the rate of discharge from the bottom of the machine is as nearly as possible uniform over the whole surface.

(*b*) That the resistance to flow throughout the machine is uniform.

To ensure uniformity of discharge requires a large number of openings spaced equally over the bottom of the machine. These openings must be large enough to prevent any tendency for them to bridge over. Some interesting experimental work has recently been done with a view to finding the shape of opening least liable to bridge, and it has been possible to effect a considerable improvement on previous practice. It has been suggested that a mechanically operated discharge gate, giving wide openings for short periods and remaining closed for longer periods, thus giving spasmodic discharges, would give greater uniformity of flow than is obtainable by present methods. Against this it is urged that a spasmodic flow is at all times difficult to deal with and that the mechanism would necessitate a drive and introduce complications in a part of the screen room where such things are often extremely inconvenient.

With regard to the resistance to the flow of grain set up in the machine by radiators and baffles, it is highly important that this should be uniform. Attempts to secure mixing of the grain by means of baffles and deflectors with a

view to securing more even heating frequently defeat their own ends by causing backwaters in which the grain never moves until the machine is emptied. In the latest type of radiator conditioner all such deflectors have been dispensed with and regular heating is secured by dividing the grain flow into thin, equally spaced streams.

Summary.

The conditioning of wheat involves "tempering," that is, improving its physical condition to facilitate milling operations. There is another object viz. the improvement of its strength but this is a bio-chemical problem and is not dealt with here. The objects of tempering are attained by regulating the amount and the distribution of moisture in the wheat, and the practical problem is how to secure most quickly and efficiently the desired amount and distribution.

Heat increases the rate of diffusion of moisture and is employed to hasten its passage either from the interior to the surface or vice-versa.

Whether the object is that of drying out or driving in moisture the temperature used should be the highest practicable and it should be maintained during the whole process.

The Methods Employed to effect heat treatment are :—

(1) Treatment by hot air which is used to convey heat to the grain and simultaneously to carry away moisture evaporated.

(2) Heating by contact with hot surfaces air being supplied as and when required to carry away moisture.

The second method has distinct advantages, especially when internal as well as surface moisture has to be removed and at all times a higher efficiency and better control can be obtained.

Efficient Treatment by Surface Heating requires—

(*a*) Sufficient heating surface.

(*b*) Proper distribution of the heating surface.

(*c*) The maintenance of the temperature of the heating surface.

Grain Flow. The grain must move at a uniform rate over the heating surface. This necessitates a uniform rate of grain discharge and the absence of all irregularities in the internal resistance to the flow of grain in the machine.

Time. In all stages of the tempering process time plays an important part. Heat reduces the time necessary for diffusion to a fraction of that required when no heat is used, but at the maximum safe temperature considerable time is required to effect :—

(*a*) Heating the grain, (*b*) the absorption of moisture, (*c*) drying, and (*d*) cooling.

The capacity of any machine, therefore, depends, not only on its heating surface and on the rate with which heat can be conveyed to the grain, but on the length of time taken by the grain to travel through the machine ; in other words, on its holding capacity.

Chapter VII.

TESTS FOR MILL STOCKS.

We now leave the problems of the cleaning and conditioning of the wheat and turn to the problems of the mill proper the breaking down of the wheat, and the sifting, purifying and grinding of the various intermediate stocks in the process of making flour and offals. The problem of the milling engineer is to provide machinery which will carry through the various operations in the way that best suits the requirements of the flour miller.

Unfortunately, when the flour miller is asked what he requires any given machine to do he can only answer in general terms. He will say, for example, that a break roller mill should break up the wheat into large flat flakes of bran on the one hand, and into clean spherical particles of endosperm on the other, with the minimum production of small particles either of endosperm or bran.

If the engineer presses him further and asks for a clear definition of the stock which the miller wants to see coming from the roller mill no answer is forthcoming. A good miller can tell by looking at the stock whether it is right, but there is no way of recording scientifically or numerically the quality of the stock. In any flour mill there are literally hundreds of different products, each of which a good miller can recognise, each consisting of a mixture of particles of various sizes and containing various proportions of bran. The variety is so great that it is hopeless to attempt any scientific definition of the different stocks.

There are, however, certain tests which are in general use, and we propose to devote this chapter to considering what these tests are, and how far they are useful to the milling engineer.

The results of a complete mill are judged by the quality and quantity of the flour and offals produced from a given wheat mixture. The chief tests as to the quality of flour from the point of view of a milling engineer are :— *

1. The colour test.
2. The baking test.
3. The ash test.

In addition to these there is a test on which the practical miller very largely relies in connection with many stocks—that of feel. A roller man setting his rolls goes almost entirely by feel. It is, however, a test in which there is no possibility of scientific record, and is therefore of no value for our purpose.

1. The Colour Test.

The most generally used test of any mill stock is its appearance or colour. By feeling the stock, and looking carefully at it, a good miller can distinguish all the stocks in a mill, and can tell at once, as regards the intermediate stocks, whether they are right, or whether some machine is not working properly.

But, as in the case of feel, when we attempt to record numerically the question of colour, we meet serious difficulties. The colour of mill stocks depends on at least five different factors, as follows :—

1. The yellowness of the endosperm, due to carrotin.

*Tests for protein, hydrogen-ion concentration, diastatic capacity, etc. are of great importance to the miller but they are tests of the chemical and biological condition of the stock rather than of any mechanical process to which it is subjected and they are not discussed here.

2. Colour of the bran, due to xanthophyll.
3. Percentage of bran.
4. Impurities present.
5. The size of the particles.

As there are five variables it is clearly impossible to give a single numerical value to any colour test which will express more than the vague and general effect of all these factors.

There are various methods in use for measuring and to some extent recording flour colour. One difficulty from which they all suffer is the difficulty of providing a permanent standard scale for purposes of comparison. There is also the difficulty that in all tests where values depend on matching of colour or tint the human element plays an important part, and it is possible for different observers to get widely different results or for one observer to vary in his readings from one day to another. While they are subject to these two possibilities, the following tests are found in practice to have considerable value.

The Pekar Test, well known to all millers, depends on the fact that dough or moistened flour becomes progressively darker when exposed to the atmosphere, particularly a warm atmosphere, for some time.

The change is less in a pure flour than in one containing a larger proportion of branny particles and this gives a simple and ready means of comparing the relative purity of stocks. By standardising the temperature and time of exposure it is possible to give colour and grade values to a series of moistened stocks. Such a figure is, however, not a true measure of the flour colour but of the presence of contaminating particles.

This has been pointed out by Bailey* who says " a quantitative measurement of the colour

*" The Chemistry of Wheat Flour "—p. 195 1925 Edition.

of such preparations (*i.e.* samples of moistened flour) while of value in classifying flours on the basis of refinement or freedom from branny particles, would not constitute a true measurement of the flour colour, nor of the bread which might be prepared therefrom."

The Pekar test is in practice a useful test of the quantity of bran, the result to some extent being modified by the colour of the bran.

The Tintometer method is a method of comparing different flours with some standard white material. Various tinted glasses are used, and numbers given for variations from the standard. This gives a numerical record of results, which includes to some extent, all the five causes of variation of colour above specified.

The colour extraction test of Kent-Jones and Herd* is on a more scientific basis, and aims at giving separately the colour of the endosperm and the colour due to the admixture of bran. It is a chemical extraction method and is not affected by impurities present apart from bran, nor by the size of the particles. Two solutions are made up, each of which is matched against a standard solution, and the colour then recorded on a scale. A figure is therefore given for the yellowness of the endosperm and another for the amount of colour due to branny particles. This latter figure is a compound one, depending partly on the depth of colour of the bran, and partly on the quantity of bran present. The test is a most useful one for recording the colour of flour in a more scientific way than is otherwise possible.

2. The Baking Test.

The ultimate test of flour is whether it can be baked into a good loaf. Every miller constantly

* "Modern Cereal Chemistry"—p. 377 1927 Edition.

uses the baking test to see whether his flour is satisfactory.

This test has, during recent years, been the subject of much investigation, with a view to arriving at standard methods. Unfortunately, however, the number of variables is again very great. It is usual to give points for :—

1. Water absorption.
2. Spring of dough during proving.
3. Stability of dough at the end of fermentation.
4. Oven spring during actual baking.
5. Gassing power during the whole period.
6. Volume of the loaf.
7. Texture.
8. Colour of the crumb of the cut loaf.
9. Colour on crust.

Consideration of results of baking tests recorded in the above manner will give the skilled baker all the information he requires as to the characteristics of any flour. It does not, however, provide a numerical record of the results.

In America some attempts have been made to overcome this objection by attributing more or less arbitrary numbers to characteristics of the flour that cannot be measured, such as texture and colour of crumb. For example, Fitz & Swanson of the Kansas Agricultural Station,* in a series of baking tests, recorded colour, texture, and thinness of cell walls by assuming the perfect loaf to have a value of 100 in each of these qualities and giving the test loaves values ranging from 80 upwards representing their comparative merit.

Any such method is, however, purely arbitrary and it is extremely doubtful whether a figure of merit based on such methods would have any real value. It is noteworthy that none of the committees in America which have considered the

*Agricultural Experiment Station Technical Bulletin No. 1. Jan. 1916

standardization of the baking test have recommended the adoption of such a system.

We have seen that as regards colour it is possible to get something approximating to a scientific record with the help of two sets of figures. As regards baking, it seems to us that nothing of the sort is practicable. There are so many variables, each of which is of first-class importance ; if the flour is badly wrong on any one of these points it may be almost useless, however good the others may be.

Quite apart from this, it is clear that the baking test is confined to finished flour. It is in no way applicable to the testing of intermediate mill stocks.

3. The Ash Test.

The ash test, although it has been known for many years, has only recently come into general use. Even now it is little used by millers in Europe, though in America the ash content of the flour is universally tested, and is regarded as a point of the first importance.

From the milling engineer's point of view, the great advantage of the ash test is that it is the only test which is just as applicable to the intermediate stocks in the mill as it is to the finished flour.

The ash test depends on two facts :—

1. That the mineral matter contained in the skin of the berry is very much higher than that contained in the endosperm, the figures being approximately 5.8% in the former case and ·32% in the latter.

2. That different wheats are fairly constant in this matter ; that is to say, that the

mineral matter in the skin is always approximately 5·8% and in the endosperm approximately ·32%.

When the carbonaceous matter of a wheat product is burnt away the mineral content is left in the form of ash, the weight of which can be determined with fair accuracy. The weight of ash produced from any given stock depends solely on the relative proportions of bran and endosperm present in the sample, and therefore affords a simple and reliable measure of the amount of bran present in the sample.

As the method of carrying out the ash test is not yet standardised, we think it desirable to describe exactly how this test is carried out in our laboratories.

Method of carrying out the Ash Test.

The product is heated in an electrically heated muffle furnace, the temperature of which is kept as close to 700°C. as possible. For this purpose a suitable pyrometer should be available and an adjustable resistance should be arranged in series with the furnace.

Five gram samples of the stock to be tested are weighed to one-tenth of a milligram in tared shallow silica or platinum dishes. When the furnace has reached the working temperature the dishes are inserted (the number should be such as just to cover the furnace floor) and the volatile matter is allowed to burn off with the furnace door open. The door is then closed to a fixed point, allowing a little air to be drawn through the furnace and escape by a chimney situated at the back. After half an hour's heating the position of the dishes is reversed, the front ones

going to the back of the furnace and so on. After an hour's heating the dishes are withdrawn, cooled in a desiccator and re-weighed.

The degree of accuracy which can be reached by this method has been carefully investigated. A large number of samples of one flour were treated in batches of five at each heating. The results of these tests are shown in Appendix IX.

As described in this Appendix we have adopted as standard a somewhat elaborate method which gives us a considerable degree of accuracy. Unfortunately, we cannot give a single figure for the maximum error because this varies with the amount of bran in the stock. As a very rough guide it would be near enough to say that :—

1. The error in the ash expressed as a percentage of the weight of the original stock is not likely to exceed ·02%.
2. The error in the ash expressed as a percentage of its own weight is not likely to exceed 6%.

Results obtained by the Ash Test.

As already mentioned the pure endosperm contains about ·32% of ash and the bran about 5·8%. Under these conditions Table I shews at a glance what percentage of bran is contained in any sample of which the ash has been determined. This table enables us to ascertain how the bran is distributed among the products of the flour mill ; for instance, if we have a mill making a straight run flour with an ash content of ·43% then the table shows us that this flour contains no less than 2% of bran. If the flour is 70% of the weight of the wheat, then the bran it contains will be 1·4% of the weight of the wheat. As

the wheat contains about 14% of bran, no less than one tenth of the bran in the wheat has been reduced by milling operations to so fine a powder as to be included in the straight run flour.

TABLE I.

ASH CONTENT %	BRAN %	FLOUR* %
.32	0	100
.34	0.38	99.62
.36	0.75	99.25
.38	1.09	98.91
.40	1.48	98.52
.43	2.02	97.98
.46	2.57	97.43
.50	3.29	96.71
.60	5.11	94.89
.80	8.76	91.24
1.00	12.4	87.6
1.50	21.5	78.5
2.00	30.7	69.3
3.00	48.9	51.1
4.00	67.3	32.7
5.00	85.5	14.5
5.80	100	0

Formula for this table:—Bran% = 18.25 × Ash% — 5.84

Table II gives ash determinations of the feed and the products of a series of purifiers. The results on the coarse semolina purifier are very striking, the throughs of the first and second sheet being almost pure endosperm, with an ash content of only just over .4%, whereas the tins and tails have both over 2% of ash. It is obvious at a glance that most of these machines are doing very useful work, but when we get to the fine middlings the advantage is less obvious. Machine B is doing good work as is shown by the relatively

*See Appendix XI. Note on Cellulose material.

low quality of the tins and tails, but there seems to be something wrong with the first sheet, as the throughs are no better than the feed of the machine. Machine A is an example of thoroughly bad work, the tins and the tails having actually a lower ash content than the feed. The results are such as to raise a very strong case for investigation as to whether the machine is properly adjusted.

We venture to suggest that a study of this table shows at once that the ash test is capable of giving an interesting and permanent record of the work done by an individual purifier, and of giving a basis for scientific comparison of the relative value of different types of purifiers.

TABLE II.

ASH TEST OF PURIFIER STOCKS

	Coarse Semo.	Med. Semo	Fine Semo.	Coarse Mids.	Fine Mids. Re "A"	Fine Mids. Re "B"
Feed	1.10	0.59	0.65	0.50	.46	.46
1st Sheet	0.43	0.40	0.37	0.41	.46	.46
2nd ,,	0.41	0.40	0.36	0.43	.43	.42
3rd ,,	0.56	0.48	0.39	0.44	.41	.38
4th ,,	0.98	0.92	0.57	0.50	.48	.46
Tins	2.16	2.44	1.40	0.81	.45	.59
Tails	2.62	2.32	1.44	0.66	.43	.55

FINELY FLUTED ROLLS.

As another example of the value of the ash test, the question of the use of finely fluted rolls in the reduction system may be cited. The following report was made on this matter some years ago :—

> In each case the percentage of ash in the feed of the centrifugal is the same, whether smooth or fluted rolls be used, but using smooth rolls there is less ash in the flour (and dunst), and more in the overtails, than when fluted rolls are

used, *i.e.* the fluted rolls cut up the bran so that it dresses out with the flour, much more than do the smooth rolls. In each case more flour is obtained using smooth rolls than with fluted rolls, so that this bran-cutting effect is not due to a greater general comminution of the stock ground.

		Smooth	Fluted
" E " Reduction	Flour	.415% Ash	.455% Ash
	Tails	.975	.860
" F " Reduction	Flour	.525	.660
	Dunst	.730	.860
	Tails	2.970	2.800

It should be added that at the same time some tests were carried out on " B " stock by the same method, and in that case no difference was found in the amount of bran powder produced by smooth rolls or fluted rolls.

These tests show conclusively how useful the ash test may be. Assuming that they were properly carried out and repeated a sufficient number of times to eliminate the possibility of chance error, the use of finely fluted rolls on " E " and " F " reductions can be finally and definitely condemned.

Chapter VIII.

BRAN POWDER.

The problem of the modern miller is to produce from wheat the maximum percentage of pure flour containing the minimum proportion of branny particles. As pointed out in Chapter I., he endeavours to achieve this by gradually breaking down the wheat, converting the endosperm as far as possible into granular pieces of semolina, and the bran into large flat flakes. Then follows an elaborate process of grading and purifying, always with a view to the separation of the bran and the endosperm, and of providing pure semolina to be ground up ultimately into flour.

The separation of the bran from the endosperm is only possible because of the tough fibrous nature of the bran which, especially when it is not too dry, makes it cohere into large flat pieces. The essential feature of the whole process is that bran can only be separated from flour on account of its flatness and size.

It seems that the specific gravities of bran and endosperm are not accurately known but their difference is not enough to enable a separation to be made between spherical pieces of bran and endosperm even when they are fairly large, still less when they are small. The result is that once the bran is broken up into pieces too small to be removed by the purifier, and is mixed with the flour, it becomes inseparable ; it can never be got out again. The unforgivable sin for any milling machine is, therefore, the making of bran powder,

and if we are to improve the milling process we must alter the working of the machines in such a way as to avoid or reduce the production of bran powder. Clearly, in order to do this effectively, we must be in a position to know when bran powder is being made, and the first step towards providing a scientific basis for the improvement of flour milling machinery is the development of a reliable test of the presence of bran powder.

A Test for Bran Powder.

We have already shown that it is possible to determine the ash content of mill stocks, and from them to calculate the amount of bran contained in any stock. It is clear that by sifting out the fine particles in the stock and then determining the amount of bran in the throughs from the sieve, we have an easy method of ascertaining the amount of bran powder present. We have adopted this method now for some years in our laboratory, and have found that it gives reliable and consistent results.*

Method of Sieving.

We use an ordinary hand sieve, which is shaken for ten minutes, the sieve being turned at right angles every two minutes, so changing the direction of shaking.

There are on the market several makes of power-driven sieves, which enable one to dispense with the laborious work of hand-sieving, but in the circumstances in which the tests are ordinarily carried out we find hand-sieving more convenient, and in spite of the apparent crudeness of the method the results obtained on any one stock have proved remarkably consistent.

* For error in estimation of Bran Powder, see Appendix XI.

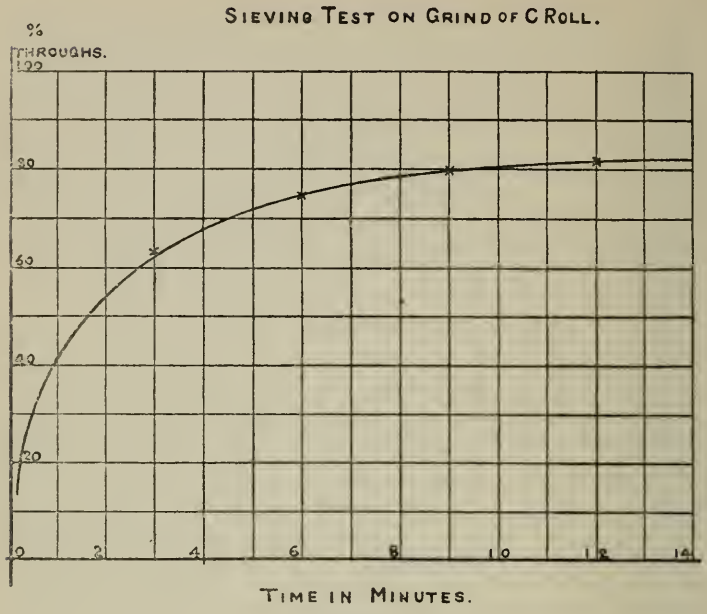


Fig. 36.
SIEVING CURVE.

Figs. 36 and 37 show the results obtained on various flours, the weight of the material passing through the sieve being plotted against the period during which the sieving has taken place. We have noted that in all cases the curve after a time becomes horizontal, that is to say, after a certain period there is no appreciable further increase in the throughs due to attrition or to any other cause. It will be noted that the time required to dress out all the throughs is longer as the silk becomes finer. It is therefore necessary to choose a fairly coarse silk in order to avoid spending much time on the sieving operation.

On the other hand, if the silk is too coarse the throughs would still include branny particles

which could be separated out by purification, whereas our object is to find the weight of the *inseparable* branny particles.

Having these two objects in mind we selected number 10 S Dufour silk, which we have used consistently as a standard throughout these tests. On the one hand this mesh is sufficiently coarse to allow the sieving operation to be finished in not more than ten minutes, whereas finer meshes require a much longer period; on the other hand, stocks that pass through this silk are so fine that the bran powder may be regarded as inseparable, while there is still a chance that purification may separate any bran particles which will not pass through the sieve.

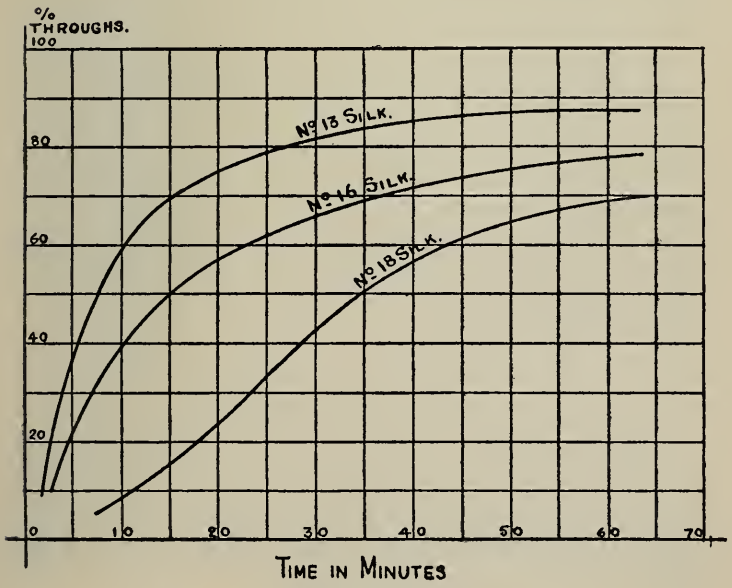


Fig. 37.
SIEVING TESTS ON DIFFERENT SILKS.

A study of Table I. will show the method followed in testing any machine and calculating the bran powder made by it. This actual test was carried out on a 2nd Break Roller Mill.

TABLE I.

	FEED.	DELIVERY.
Weight of sample*	100 grams.	100 grams.
Throughs of 10 S silk ...	1.8 "	13.2 "
Ash Content of Throughs ...	.65 %	.47 %
Corresponding Bran Content of Throughs (*see Table I. Chapter VII.*)	6 %	2.8 %
Actual Bran Powder Content of whole sample ...	.11 grams.	.37 grams.

The Table shows ·11 grams of bran powder in the feed and ·37 grams in the delivery ; in other words, ·26 grams of bran powder have been made from 100 grams of feed. The method of calculating the bran powder is clearly shown in the table ; the same method has been followed throughout the tests on which the remainder of this chapter has been based.

RESULTS OBTAINED.

Table II. shows the amount of bran powder produced on certain purifiers, centrifugals, elevators and worms. It will be seen that the quantity produced by these machines, although not negligible, is still extremely small.

* The weight of the necessary sample of feed, in such a case as the above, is greater than the sample of the delivery because the feed contains a relatively small percentage of stock fine enough to pass through a No. 10 S silk and a large sample must be taken to secure enough throughs for a satisfactory ash test. For the sake of clearness in the above table the quantities are stated in terms of samples of 100 grams. for both feed and delivery.

TABLE II.

MACHINE.	BRAN POWDER PRODUCED % OF FEED.
C. M. Purifier	.06
X2 Centrifugal	.05
IV. Sc. Elevator	.02
Y. Elevator	.02
J. Elevator	.03
IV. Sc. Worm	.07
X.1 Cent.	.08

STONE MILLS *versus* ROLLER MILLS.

In order to obtain a comparison between the amounts of bran powder produced by a stone mill and by a roller mill, ash tests were made on a sample of flour obtained from stone-ground wheatmeal by dressing it through 10 S silk. The results showed an ash content of .72 %. This compares with an ash content of .42 % for straight-run roller mill flour and with .54 % for 1st break roller mill flour. A comparison between these figures is misleading, because :—

(*a*) While the stone-ground flour contained the whole endosperm mixed with the bran, much of the bran had been removed from the roller mill grist by purification before the final reduction to flour ; therefore the figure for the straight run flour would be unduly low.

(*b*) A comparison between stone-ground flour and 1st break roller mill flour favours the former. In breaking down the wheat on a roller mill, by far the greater proportion of the endosperm is released as semolina

and not as flour ; all the bran is subject to attrition and the resultant bran powder is dressed out with the comparatively small proportion of endosperm which is reduced to flour. Consequently, the ash content is unduly high.

If it were possible to make on roller mills a similar product to stone-ground flour, its ash content would lie between .42 % and .54 %, as compared with .72 % mentioned above. This shows that stone mills produce a far greater proportion of bran powder than roller mills.

Results Obtained on a Complete Flour Mill.

In an endeavour to find out at what points in the mill and in what quantities bran powder is made, we carried out an elaborate series of tests on a good modern mill. It was a mill producing 15 sacks (each of 280 lbs.) of flour per hour, well adjusted and giving probably as good results as any mill in England, that is to say, making probably as little bran powder as can be made, having regard to present day knowledge of the art of flour milling.

The results of these tests are summarised in Table III. On the one side is given the amount of bran powder produced by the various machines, and on the other side the bran powder in the flour.

Looking first at the right hand side of the table, we see in column V. that 4,200 lbs. of flour were produced per hour, and in column VI. that this flour contained 83.7 lbs. or almost exactly 2 % of bran powder, varying from under 1 % in the top quality to nearly 6 % in the low grade flour.

	I.	II.	III.		IV.		V.	VI.	VII.
	Stocks.						Output of Flour.		
Machine.	Feed.	Bran Powder.						Bran Powder.	
	Lbs. per Hour.	Produc'd % of Feed.	Produced lbs. per Hour.		Produced. % of Total Bran Powder		Quality of Flour.	Quantity of Flour lbs. per Hour.	Q'ntity lbs. per Hr.	Content as % of Flour.
Break System—1st Bk. Rolls ...	6,000	0.20	12.0		14.3		Top	2,270	19.3	0.85
2nd Bk. ,, ...	4,500	0.24	10.8		12.9		Medium	1,260	25.2	2.0
3rd Bk. ,, ...	2,160	0.30	6.5		7.8		Low	670	39.2	5.85
4th Bk. ,, ...	870	0.58	5.0		6.0					
X 1 ,, ...	180	0.21	0.4		0.5					
X 2 ,, ...	300	0.16	0.5		0.6					
Y ,, ...	280	0.30	0.8	36.0	0.9	43.0				
Reduction System—A. Rolls ...	2,050	0.13	2.7		3.2					
B. ,, ...	1,100	0.17	1.9		2.3					
B2 ,, ...	500	0.46	2.3		2.7					
C. ,, ...	1,000	0.34	3.4		4.1					
D. ,, ...	650	0.56	3.6		4.3					
E. ,, ...	550	0.60	3.3		3.9					
F. ,, ...	350	0.50	2.5		3.0					
G. ,, ...	375	(0.6)	2.3		2.7					
H. ,, ...	200	0.45	0.9		1.1					
J. ,, ...	250	0.62	1.6		1.9					
K. ,, ...	375									
L. ,, ...	200	(0.7)	4.8	29.3	5.7	34.9				
M. ,, ...	100									
Other Plant—										
Elevators	20,000	0.025	5.0		6.0					
Reduction Cents....	7,700	0.05	3.8		4.6					
Unaccounted for (Plansifters, Purifiers, Break Cents., Worms, etc.)			9.6	18.4	11.5	22.1				
Total	6,000	1.40	83.7		100.0			4,200	83.7	2 %

To put this in another way, the hourly feed to the mill consists of 6,000 lbs. of wheat which contains about 14 % of bran. There would accordingly be 840 lbs. of bran in the hourly feed to the mill; of this 83.7 lbs., or 10 % is turned into bran powder and mixed with the flour. This gives the measure of the inefficiency of milling in the best modern flour mill; instead of completely separating the bran from the endosperm, no less than one-tenth of the bran is ground up and mixed with the flour.

We now turn to the left hand side of the table to find out which of the machines is responsible for the production of bran powder. This is best seen from column III. which gives, in lbs. per hour, the bran powder produced by the principal machines. It will be seen that tests were made on all the different roller mills; also on the elevators and reduction centrifugals. No tests were made on the remaining machines—plansifters, purifiers, break centrifugals, worms, etc. The figure of 9.6 lbs. per hour set against the sundry machines is obtained by difference.

It will be noted that the bran powder produced on the various machines is given as a percentage of the total bran powder produced; we find that 43 % of the total is made by the break rolls, and 35 % by the reduction rolls. In other words, a total of no less than 78 % of all the bran powder is made by the roller mills.

It has, of course, always been known, or at least assumed, that roller mills were the chief sinners in this respect, but we believe that no attempt has ever been made to show quantitatively what proportion of the bran powder is produced by the roller mills.

Millers are continually discussing such questions as the amount of damage done to the flour by

elevators, still more by worms, not to mention the age-long controversy of centrifugals *versus* plansifters. This table shows for the first time that all the other machines together, including all the transport in the mill, are responsible for only one-fifth of the production of bran powder, whilst the roller mills are responsible for four-fifths. This seems to us a new fact of the utmost importance. It is quite clear that the weak spot in the modern flour milling system is the roller mill. After all this is only reasonable. The function of the rolls is to grind and tear the wheat berry into flour and in doing so they subject, not only the endosperm, but the bran, to considerable pressure and tearing action, compared with which the action of any other machines used in the modern mill is gentleness itself.

We have shown above how extraordinary is the difference in the purity of the flour which can be made in a roller mill as against that made in the old stone mill. The results of our tests make it clear that while there is no room for corresponding improvement in the future, yet there is room for great developments, and these developments are likely to consist mainly in reducing the amount of bran powder produced by roller mills.

Clearly this can be done in two ways. The first is to improve the roller mill itself so that with a given stock it will do its work with the production of less bran powder; the second is the improvement of the other machines, or of the system of the mill, so as to send purer stocks to the rolls.

It is interesting to note that the break rolls are the worst offenders, making 43 % of the bran powder, whereas the reduction rolls make 35 %. On the other hand, the reduction rolls actually convert a larger proportion of the bran which is

fed on to them into bran powder than do the break rolls. It will be noticed that the bran powder produced on the first three breaks averages about 0.25 % of the feed, whereas the bran powder produced by the reduction rolls from B2 down to the tail of the mill averages over 0.5 % of the feed.

On the other hand there is so much more bran in the feed of the break rolls that as individual machines they make far more bran powder than the individual reduction roller mill, the 1st and 2nd breaks between them making 27 % of all the bran powder produced in the mill.

The results shown by this table are admittedly preliminary and tentative, though we think that further work will show that they are not far wrong. It seems to us that for the first time they open the way for a steady scientific attack on the errors which still exist in the modern flour mill. As an instance of the way in which scientific progress can be made by the help of the bran powder test we give the two following examples.

We may refer firstly to the question of fine fluting for reduction rolls, already mentioned in Chapter VII. In this case the work was done by means of the ordinary ash test, and a fairly definite result was arrived at showing that finely fluted rolls are a positive disadvantage on certain stocks. A few years ago many millers, under the influence of a temporary fashion, used finely fluted rolls on these stocks, whereas a scientific test would almost at once have shown them that they were doing definite harm to the results of their mill.

Coming to the question of the break rolls, we have made a series of preliminary tests to investigate the question as to how the production

of bran powder is influenced by different conditions of roll surfaces.

Tests were made with the rolls set as follows :—

1st Break.

1 pr. new rolls running sharp to sharp, in use 6 wks
1 ,, ,, ,, ,, dull to dull ,, 6 ,,
1 ,, old ,, ,, sharp to sharp ,, 72 ,,

3rd Break.

1 ,, new ,, ,, ,, ,, ,, 6 ,,
1 ,, old ,, ,, ,, ,, ,, 185 ,,

4th Break.

1 ,, new ,, ,, ,, ,, ,, 6 ,,
1 ,, old ,, ,, ,, ,, ,, 72 ,,

On the 1st Break the new rolls running dull to dull and the old rolls running sharp to sharp were both working well, and made just about the same amount of bran powder, but new rolls running sharp to sharp produced much more bran powder. On the 4th Break similar results were found, but on the 3rd Break there was no difference between the new and the old rolls. It will be seen from the summary of the tests given above that the 3rd Break old rolls had been in use for $3\frac{1}{2}$ years against $1\frac{1}{2}$ years in the cases of the 1st and 4th Break rolls. It is possible that the 3rd Break rolls had worn to a point at which they were again producing excessive bran powder. If this is so, periodic bran powder tests should be a useful guide to the miller as to the condition of his fluted surfaces and as to the best time for re-fluting.

These tests would appear to justify the practice of running new rolls dull to dull for a time before running them sharp to sharp. This must, however, be regarded as tentative. Further work on these lines should lead to valuable results. All milling engineers and many millers have at various

times experimented with different sizes and shapes of flutes, different spirals, differentials, and so on. The results have almost always been inconclusive because they have generally not been of sufficient magnitude to influence appreciably the results of the mill as a whole, and there has been no way of recording the results of each individual alteration. Unless by chance, which is unlikely, we have arrived by purely empirical methods at the best conditions as regards break rolls, we can look forward with a good deal of confidence to considerable improvement in this matter, with the help of the bran powder test.

We attach considerable importance to the bran powder test and to the analyses as to the production of bran powder by various machines as shown in Table III. Although the results must be regarded to some extent as tentative, yet we believe that we have shown the method to be intrinsically a sound one. It is no doubt somewhat laborious, and therefore expensive to carry out, but we believe it to be a method which those closely connected with the progress of the industry, and in particular milling engineers, can and will develop to the advantage of the milling trade.

Chapter IX.

PURIFICATION.

The object of the purifier is to prepare the stocks for the reduction roller mills by freeing them as far as possible from branny particles, so sending the stocks in the purest possible form to the roller mills.

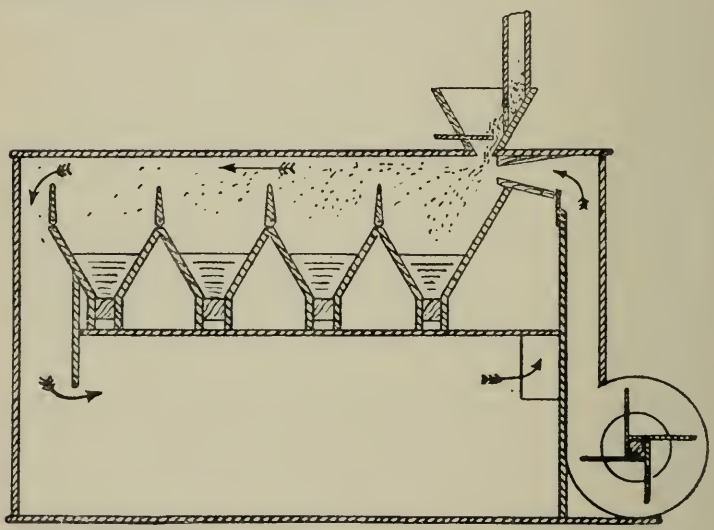
It is true that by simply grading the broken stocks that come from the break rolls, and passing these on direct to reduction rolls, fairly good results can be achieved, results very much better than were possible with the stone mill. Even to-day there are mills making some sort of a living in competition with complete modern flour mills without the use of the purifier.

We have, however, shown in Chapter VIII., Table III., that 35 % of all the bran powder which gets into the flour is produced on the reduction rolls. In one sense the reduction roller mills are the worst sinners in the production of bran powder because a simple calculation based on the above table shows that whereas the 2nd break roller mill converts only .8 % of the bran in the feed into bran powder, F roll converts no less than $2\frac{1}{2}$ % of the bran in the feed to inseparable powder, which goes straight into the flour. The importance therefore of sending the minimum amount of bran to the reduction rolls is obvious. It is probably true to say that wherever by means of purification any bran is kept away from the reduction rolls there will be a substantial reduction in the total amount of

bran powder produced, and therefore a substantial improvement in the reduction flour.

Early Purifiers.

The earliest attempts at purification of which we have records were based on the principle illustrated in Fig. 38. A horizontal current of air was drawn through a falling curtain of stock, and over a series of hoppers arranged to receive the separated materials.



Old Type Aspirator Purifier.
Fig. 38.

Under such conditions the distance which a particle will be carried before it falls depends on the ratio of its terminal velocity in air to the horizontal velocity of the air current. For similar particles, the smaller the particle the further it will travel. Roughly speaking, where four hoppers are provided, the kind of separation which might be expected when treating unpurified semolina is as follows :—

First Hopper.
Large pieces of endosperm—pure.

Second Hopper.
Medium pieces of endosperm and large pieces of endosperm with loose bran adhering.

Third Hopper.
The finest pieces of endosperm, medium pieces of endosperm with loose bran adhering, and the heaviest bran particles.

Fourth Hopper.
The finest pieces of endosperm with loose bran adhering, bran flakes, and particles except dust and fine material carried away by the air stream.

In actual practice, owing to the unavoidable turbulence of the air current and to the adhering together of particles in the feed (especially with the finer stocks) the separations were much less accurate than indicated above.

On examining the above theoretical separations it will be seen that if the deposits in the second and third hoppers were graded according to size it would be possible to separate medium pieces of endosperm from large pieces with bran adhering, and the finest pieces of endosperm from the medium pieces with bran adhering and from the heaviest bran. For this reason an early step in the development of the purifier appears to have been a combination of grading and aspiration. The stock to be dealt with was first passed over a sieve having two or more covers which divided it up into three or more grades. The throughs from each cover passed to separate air purifiers or to separate sections of one purifier and were there graded according to their air resistance.

Machines of this type gave much better results than the single machine and they were in general use for many years.

It was found, however, that the air separations were imperfect because (*a*) the air current did not move with equal velocity at all points where it passed through the feed, and (*b*) the curtain of stock through which the air was drawn set up a varying resistance owing to the particles of which it was composed tending to crowd together into clusters.

The next development was an attempt to secure more uniform air currents and at the same time to break up the stream of feed by increasing the number of aspirations to which the stock was subjected. This was done by allowing the stock to fall over louvres through which the air was

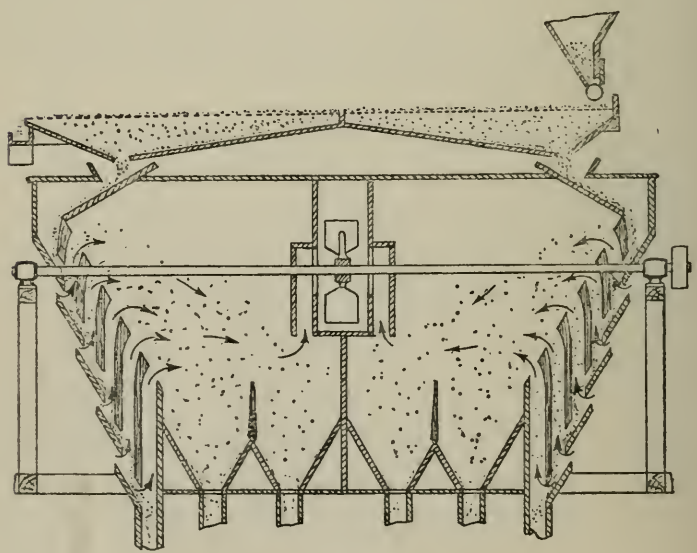


Fig. 39.

LOUVRED TYPE OLD ASPIRATOR PURIFIER.

drawn. Hitherto the direction of the aspirating air current had been horizontal, but in the louvred machines it was changed to nearly vertical.

The principal on which this machine worked will be apparent from the diagram Fig. 39.

The final big step was to combine the two operations of grading and purifying by drawing a current of air vertically upwards through the sieve and stock on it whilst the latter was being graded. This made it possible to get much more uniform air currents and largely overcame the difficulty arising from unequal resistance set up by the stock, the movement of the sieve keeping the stock in a state of agitation and preventing coherence. This is the characteristic principle of the modern purifier.

The Modern Purifier.

The modern purifier consists essentially of a grading sieve, having its length divided into four or more approximately equal sections, which have perforated covers progressively coarser from head to tail of the sieve. Through this sieve, and the stock travelling over it, is passed a vertical current of air, the strength of which is adjusted for each section. This allows smooth hard particles of the correct size to fall through the holes but prevents similarly sized particles, with pieces of bran attached, from doing so. At the same time the air lifts out of the stock the fine, dusty particles and light flakes of bran, etc. The vertical air current is obtained by arranging the sieve below a hood to which it is connected by a flexible air-tight joint. The hood, *viz.*, the space above the sieve, is exhausted and the space below the sieve is open to the atmosphere. The hood is divided into compartments corresponding to the sec-

tions of the sieve and each compartment communicates by a separate valve with an exhaust trunk. In this way the strength of the air currents through each section can be adjusted separately. The overtails from the sieve are usually subjected to a light aspiration before being spouted away.

Below the sieve is placed a hopper with a worm conveyor and two or more spouts are provided so that the throughs of the different sections can be combined in the most suitable way for subsequent milling operations.

Close above the sieve it is usual to arrange the so-called "tins," a series of parallel troughs between which the air passes on its way to the exhaust trunk. The heavier particles lifted out of the stock by the air are deposited in the tins, and are either shaken or swept away to discharge spouts. The finer particles are collected partly by a scraper in the exhaust trunk and partly by the dust collector into which the air from the purifier is discharged.

Fig. 40 shows diagrammatically the arrangement of such a purifier.

Sieve Motion.

It is clear that to obtain the best effects from the air current, the sieve must be completely covered from head to tail with an evenly distributed coating of stock and, as the pure particles of endosperm are dressing through all the way down, the thickness of this coating must be considerably greater at the head than at the tail end of the sieve. For this reason the air current at the head is much less effective than it is lower down the sieve and there is a greater tendency for impure particles to dress through at that end than further down.

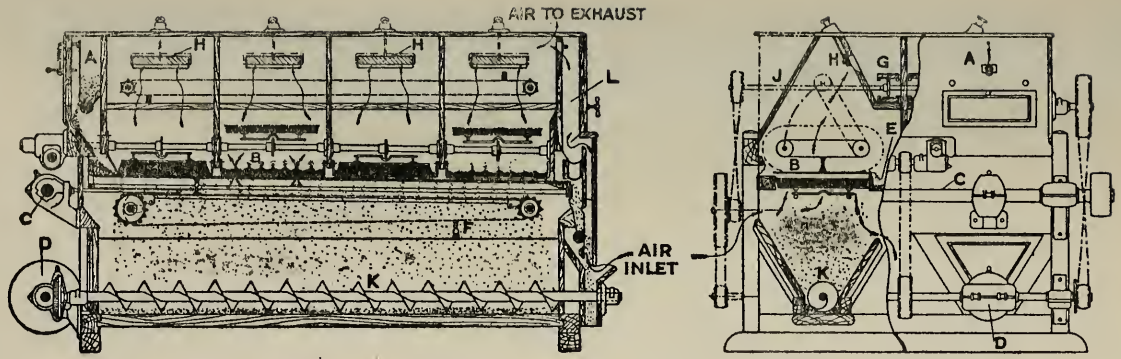


Fig. 40.

DIAGRAM OF FANLESS PURIFIER.

(A) Feed hopper.
(B) Brush-cleaned tins over the sieve.
(C) Eccentric shaft.
(D) Worm cross gear.
(E) Side channel collecting from the tins.
(F) Sieve brush.
(G) Longitudinal air trunk.
(H) Air valve.
(J) Glass inspection door.
(K) Collecting worm.
(L) Tail aspiration.

At one time an attempt was made to overcome the difference in thickness of the stock at head and tail of the sieve, by tapering the sieve in width from head to tail. Apart from the obvious constructional disadvantages of such an arrangement, difficulties were encountered in keeping the stock uniformly distributed across the sieve, especially with the finer grades, and after a few years the arrangement was abandoned in favour of the parallel sieve.

It has been found that when the motion of the sieve is such that it has the minimum vertical movement, *viz.*, if when in mid-stroke the hangers carrying the sieve are vertical, the stock does not travel so well as when there is a greater vertical component in the motion of the sieve. This increased vertical component is obtained by setting the sieve so that when in mid stroke the hangers are inclined, the points at which the hangers are attached to the sieve being some distance further from the head end than the points on which they are supported. This gives the sieve an upwardly inclined movement as it travels *from* the head and a downwardly inclined movement on the return stroke. The amount of this inclination, that is the ratio between the vertical and horizontal movement of the sieve, is very important. It varies for different stocks and with the sieve speed. If it is too large, that is to say, if there is too much vertical movement, the stock travels down the sieve in big leaps. If, on the other hand, there is too little vertical movement, the stock lies dead on the sieve and the points at which it is aspirated are few and far apart, allowing impure stock to dress through.

The ratio between the vertical and horizontal movement can be very simply and effectively adjusted by the well-known method of moving

the points of suspension of the sieve on the stepped blocks which form supports for the sieve hangers.

Air Currents and Their Action.

The individual particles forming the layer of stock on the sieve are so closely packed, especially in the finer grades, that if a uniform air current of sufficient velocity to effect the desired separations could be drawn through, the difference in the air pressures below and above the sieve would be sufficient to lift the stock completely off it. Actually, owing to its state of agitation on the sieve, the thickness and compactness of the stock are continually varying from point to point. In consequence the air is continually breaking through the film at the thinnest points and forming, as it were, miniature eruptions. The heavy particles thrown up in this way immediately fall back to the sieve and help to reform the layer of stock, and the light particles are carried away by the general upward trend of the air, and are deposited in the tins or dust collector. As a result the surface of the stock presents a granular or mottled appearance reminiscent of the surface of a viscous liquid when boiling.

The more numerous the eruptions and the more uniform their distribution over the surface of the stock, the less will be the difference in the velocity of the gusts of air breaking through, the more often will the particles be subjected to the action of the air and, consequently, the better will be the work done by the machine.

In these eruptions, the particles of stock thrown up by the air gusts are well separated from each other and surrounded by the rushing air. Under such circumstances a very searching separation is possible ; light particles are carried away in the air current and heavier ones inevitably fall back

or out of the air gusts and there is little chance of any such being carried away by adhering to a lighter particle. If, however, the action of the air current at any point or points is too strong there is a danger of good stock being carried into the tins. This can be avoided by adjusting the strength of the air current and arranging that, as far as possible, it is uniform in every part of any one section.

From the above considerations it will be evident that in order to obtain the best results certain conditions must be fulfilled and these may be summarised as follows :—

(1) It is essential that there should be sufficient stock on the sieve to maintain a uniform layer over the whole area. If this is not done, the air currents tend to pass through the sieve at thinly covered points only, lifting all the stock from the sieve there and leaving the rest unaspirated.

(2) The sieve should be truly level from side to side, otherwise the layer is thicker on the low side and most of the air passes through the high side.

(3) For a given stock and a given sieve speed there is a correct ratio of vertical to horizontal travel of the sieve which gives the necessary agitation to the stock and permits of the best and most uniform aspiration.

(4) It is most important that the air pressure in any one section should be uniformly distributed over the sieve, otherwise impure stock will be dressed through at points where the air pressure is low and good stock will be lifted out at points where it is high.

Work of the Purifier.

Before proceeding to consider the method of testing the work of a purifier, it may be useful to summarise here in detail the work that the purifier is expected to perform and to note what are the errors most likely to occur.

A purifier, in a fairly simple purification system, should separate from the mass of stock and group together the following products :—

(1) *Throughs of Head Sheets.*
All granular particles of endosperm free from adhering flakes of bran or cellulose material.
The most likely error here will be the inclusion of particles of endosperm with small adhering flakes of bran.

(2) *Throughs of Intermediate or of Tail Sheets.*
All particles of endosperm with adhering flakes of bran. There is no rigid line between this group and the next.
The most likely error will, therefore, be the inclusion of particles of pure endosperm.

(3) *Tails, or Tails with Cut-off from the last Sheet.*
All flakes of bran and cellulose material with an adhering layer of endosperm. Here, there is no rigid dividing line between this and the preceding and following groups, and the opinion of millers differs considerably as to what should be included.
The most likely error is the inclusion of flakes of bran free from adhering endosperm.

(4) *Tins Separation* (*Heavy Aspirations*).
The composition of this group varies considerably with the nature of the stock. With the coarser stocks it consists mostly

of small bran flakes free from endosperm and flakes of cellulose material forming the outer skin of the berry. With the finer stocks it consists chiefly of very small particles of bran and cellulose material both with and without adhering endosperm.

The most likely error is the inclusion of an excess of endosperm particles.

(5) *Dust Collector Separations.*
All dust particles, from whatever source, with light flakes of cellulose material.

The most likely error is the inclusion of small endosperm particles which should have been dropped in the tins.

Method of Testing.

To make an accurate comparison of the work done by two purifiers it is necessary that the feed to both machines should be the same as regards quantity and composition. This result can best be obtained by arranging the machines to be tested so that the same stock can be fed alternately to each machine. In order to minimise the effect of irregularities in the amount and composition of the stock, it should be fed to each machine for several equal periods during the test.

Results of tests of this kind have hitherto, so far as we know, been judged purely by eye, and with two purifiers working next to one another. On the same stock, it is easy in this way to tell which is doing the better work, but of course no numerical record of such results can be kept.

This is, however, a case for which the ash test is particularly suitable; the whole object of purification is to get rid of branny stocks, and a measure of the weight of the various stocks con-

cerned, coupled with an ash test, gives a numerical record of the work of the purifier. Its one weakness for this purpose is the error introduced by the presence of cellulose or beeswing; Appendix XII. shows that this is of no serious importance.

Results of Tests.

With a view to determining whether the method of testing could be relied on to give consistent results, a series of tests was made on an experimental purifier of the type described below under "C." The results are shown in Table I.

Table I.

Comparison of Different Tests on the Same Machine.

Stock—Coarse Semolina. *Machine—"C."*

Item.	Test 1.		Test 2.		Test 3.	
	Quantity lbs./hr.	Ash Content %	Quantity lbs./hr.	Ash Content %	Quantity lbs./hr.	Ash Content %
Feed ...	952	.98	952	.98	1075.5	.88
1st Sheet ...	111	.45	105	.43	120	.44
2nd ,, ...	204	.46	201	.45	229	.44
3rd ,, ...	243	.76	238	.64	262	.65
4th ,, ...	327	1.66	330	1.20	379	1.47
Tails ...	62	2.83	72	2.64	80	2.74
Aspirations	0.3	2.09	0.5	2.12	0.25	1.93
Filter ...	4.7	2.21	5.5	2.55	5.25	1.87

Tests 1 and 2 were made on the same day, 1—being the results obtained with the machine adjusted with the care taken in the average mill, and 2—those obtained with the machine adjusted to give the best results judged by a systematic comparison of samples. Test 3 was made at a later date when the wheat mixture had been changed ; the adjustment of the machine was the same as in Test 2.

Examining the figures in Table I. it will be noted that, as a result of the more careful adjustment for Test 2, the average ash content of the throughs from the sheets was reduced from .98 % to .78 %, the ash in the tails reduced from 2.83 % to 2.64 %, while the ash in the liftings increased from an average of 2.20 % to an average of 2.51 %. This shows the value of careful adjustment. In spite of the difference in the feed the results of Test 3 are very similar to those of Test 2, where the setting was the same.

The above results show that one may be reasonably sure that the method of testing described is both delicate and accurate enough to give a valuable comparison of the work of different machines.

Tests on Purifiers With and Without Tins.

The standard purifiers in this country have, for many years, been fitted with tins which are designed to make the distribution of the air currents over the sieve more even, and which catch the heavier liftings, separating these from the very light liftings which go to the filter dust collector. On the other hand, in America no such tins are used, the sieve being left open, and it is also the practice of some of the Continental milling engineers to build purifiers without tins. These

have a considerable advantage in the visibility of the stock on the sieve, and the further advantage of saving the cost and complication of the tins. Perhaps the most interesting question in connection with purifiers to-day is whether a tinless purifier can be made to give as good results as the standard machine, or whether the addition of tins justifies the additional cost.

In order to answer this question we have made a series of tests, and have actually constructed two special types of tinless machines in order to endeavour to overcome the difficulties inherent in this type. We think a summary of our experiments and tests in this matter may be of interest.

Tests were carried out on four machines altogether :—

(A) A standard Simon Purifier fitted with tins.

(B) A standard tinless machine, well constructed from an engineering point of view, in which all the liftings go direct through a high velocity channel to the dust collector.

(C) A specially designed tinless machine arranged to give the most even possible air currents over the sieve, and fitted with a large air trunk in which the heavier liftings are deposited so as to give a separation analagous to that obtained on the tins.

(D) A machine with a small high velocity air trunk stretched right across the sieve at the tail end of each compartment, so as to carry away all the excess matter which is left on the silk by the ordinary tinless machine. A considerable number of these machines are at work in a large mill, and are giving excellent results.

Table II.

Comparison of Purifiers "A" and "B."

Stock—Fine Mids. re-purification.

	Machine "A."				Machine "B."			
	Weight†	Ash Content %	Bran Content. See Table I., Chap. VII		Weight†	Ash Content %	Bran Content. See Table I., Chap. VII	
			%	Actual Weight†			%	Actual Weight†
Feed	100	.43	2.02	2.02	100	.41	1.66	1.66
1st Sheet Throughs	5.6	.42	1.84	.103	8.2	.40	1.48	.121
2nd ,, ,,	22.2	.39	1.29	.287	14.8	.38	1.09	.161
3rd ,, ,,	30 (75.1)	.42	1.84	.552 (1.198)	23.3 (62.7)	.39	1.29	.301 (.826)
4th ,, ,,	17.3	.40	1.48	.256	16.4	.40	1.48	.243
Tails	18.8 (23.5)	.47	2.75	.517	35.9	.45	2.39	.858
Tins	4.7	.57	4.57	.214 (.731)	—	—	—	—
Filter*	(1.4)	—	—	—	(1.4)	—	—	—

Throughs of all sheets to C Rolls.
Tails and Tins to 4th Break Scalper.
Filters to Offal.

* No measurements could be made on material carried away to Filter in either case.
The figures shown in brackets are obtained by difference.
† All weights are expressed as percentages of the feed.

It should be added that all the tests were made against two standard Simon purifiers, one on fine middlings re-purification, and the other on coarse semolina. It was felt that these two rather extreme stocks could be regarded as representative.

Note.—We have not gone to the expense of testing an American purifier because our experience of the results obtained in practice is such as to convince us that these machines are definitely inferior.

Standard Purifier *versus* Standard Tinless Purifier.

The results of this are shown in Table II. It will be seen that the standard machine fitted with tins sends 75 % of the stock to C rolls, whereas the tinless machine was only able to send 62.7 % ; the ash content in both cases was practically the same. The remainder of the feed had to go to the 4th break scalper. This proves the substantial superiority of the standard machine over the tinless machine.

Standard Purifier *versus* Improved Tinless Purifier.

The result of the next test is shown in Tables III. and IV., and is a comparison of the standard machine against the improved tinless machine in which air currents are as well distributed as it is possible to get them. Examining first the results obtained on fine mids. re-purification (Table III.) it will be seen that there was not much difference as regards the materials sent from the 1st and

Table III. Comparison of Purifiers "A" and "C."

Stock—Fine Mids. re-Purification.

	Machine "A."				Machine "C."			
	Weight†	Ash Content %	Bran Content. See Table I., Chap. VII		Weight†	Ash Content %	Bran Content. See Table I., Chap. VII	
			%	Actual Weight†			%	Actual Weight†
Feed	100	.46	2.57	2.57	100	.46	2.57	2.57
1st Sheet Throughs	19.5 } 40	.46	2.57	.50 } .95	17.5 } 38.5	.46	2.57	.45 } .84
2nd ,, ,,	20.5 }	.44	2.20	.45 }	21 }	.42	1.84	.39 }
3rd ,, ,,	22 } 39	.43	2.02	.45 } .76	24.5 } 36	.40	1.48	.36 } .72
4th ,, ,,	17 }	.42	1.84	.31 }	11.5 }	.49	3.10	.36 }
					11.5 }	.49	3.10	.36 }
Tails	8.3 } 19.3	.53	3.84	.32 } .84	8.4 } 21.3	.55	4.20	.35 } .78
Aspirations ...	11.0 }	.58	4.75	.52 }	1.4 }	.59	4.93	.07 }
Filter*	(1.7)	(.51)	3.48	(.06)	4.2	.52	3.66	.15

"A" Machine Throughs of 1st and 2nd Sheet to C Roll.
,, ,, 3rd and 4th ,, D ,,
Tails and Aspirations to 4th Break Scalper.
Filter to Offal.

"C" Machine Throughs of 1st and 2nd Sheet to C Roll.
,, ,, 3rd and half 4th ,, D ,,
,, ,, half 4th Sheet, Tails and Aspirations to 4th Break Scalper.
Filter to Offal.

* No measurements could be made on material carried away to Filter for "A" Machine. The figures in brackets are estimated.

† All weights are expressed as percentages of the feed.

TABLE IV. COMPARISON OF PURIFIERS "A" AND "C."

Stock—Coarse Semolina.

	Machine "A."				Machine "C."			
	Weight†	Ash Content %	Bran Content. See Table I., Chap. VII		Weight†	Ash Content %	Bran Content. See Table I., Chap. VII	
			%	Actual Weight†			%	Actual Weight†
Feed	100	.98	12.05	12.05	100	.98	12.05	12.05
1st Sheet Throughs	9.7	.45	2.39	.23	11.2	.44	2.20	.25
2nd ,, ,,	17.2 } 34.9	.45	2.39	.41 } .96	21.3 } 40.6	.44	2.20	.47 } 1.21
3rd ,, ,,	8.0	.54	4.02	.32	8.1	.65	6.03	.49
	16.0 } 44.8	.54	4.02	.64 } 4.27	16.2 } 33.8	.65	6.03	.98 } 4.67
4th ,, ,,	28.8	1.01	12.60	3.63	17.6	1.47	20.97	3.69
					17.6 } 25.1	1.47	20.97	3.69 } 6.99
Tails	19.9	2.16	33.61	6.68	7.5	2.74	44.19	3.30
Aspirations ...	.11 } .40	1.91	29.02	.03 } .11	.02 } .5	1.93	29.39	.01 } .15
Filter*	(.29)	(1.9)	(29)	(.08)	.48	1.87	28.29	.14

"A" Machine Throughs of 1st, 2nd and one-third of 3rd Sheet to A Roll.
,, Two-thirds of 3rd and 4th Sheet to X Roll.
Tails to Y Roll.
Aspirations and Filter to Offal.

"C" Machine Throughs of 1st, 2nd and one-third of 3rd Sheet to A Roll.
,, Two-thirds of 3rd and half of 4th Sheet to X Roll.
,, Half of 4th Sheet and Tails to Y Roll.
Aspirations and Filter to Offal.

* No measurements could be made on material carried away to Filter for "A" Machine. The figures in brackets are estimated.

† All weights are expressed as percentages of the feed.

2nd sheets to C roll. The 3rd sheet was actually better in the tinless purifier, but when we come to the 4th sheet we at once find a serious drop. The ash content in the purifier fitted with tins is .42%; in the tinless machine it has jumped up to .49 %, and is so high that the miller found it necessary to send half the throughs of the 4th sheet to the 4th break scalper. If we look at the aspirations we find that on the machine fitted with tins, 11 lbs. have been lifted, whereas on the tinless machine only 1.4 lbs. have been lifted. Adding together the aspirations and the filter it has been possible to lift 12.7 lbs. on the machine with tins, as against only 5.6 lbs. on the tinless machine. It is the removal of these impure stocks which renders possible the good work on the 4th sheet of the machine with tins, and their non-removal which spoils the work of the 4th sheet of the tinless machine.

The results obtained with coarse semolina purifiers, Table IV., show a similar result, although in this case the aspirations are much less. The first two sheets are similar; on the 3rd sheet the results of the tinless purifier are a little worse; on the 4th sheet they are much worse.

The results of both sets of tests point to the same weakness in the tinless machine, *viz.*, deterioration of the work on the 3rd and especially the 4th sheets, due to the failure to remove bran by aspiration in the early stages. It is to be noted that the aspirations on the head sheets were just as strong on the tinless as on the machine with tins; if they had been stronger the work would have suffered. The difference was simply due to the action of the tins in catching the liftings at the head end of the machine, whereas in the tinless machine all the heavier liftings simply fell back on to the stock.

Table V. Comparison of Purifiers "A" and "D."

Stock—Fine Mids. re-purification.

	Machine "A."				Machine "D."			
	Weight†	Ash Content %	Bran Content. See Table I., Chap. VII		Weight†	Ash Content %	Bran Content. See Table I., Chap. VII	
			%	Actual Weight†			%	Actual Weight†
Feed	100	.42	1.84	1.84	100	.42	1.84	1.84
1st Sheet Throughs	15.8	.35	.56	.09	16.8	.36	.75	.13
2nd „ „	18.7 } 34.5	.39	1.29	.24 } .33	24.2 } 41.0	.36	.75	.18 } .31
3rd „ „	24.5	.39	1.29	.32	29.0	.41	1.66	.48
4th „ „	21.0 } 45.5	.41	1.66	.35 } .67	13.9 } 42.9	.43	2.02	.28 } .76
Tails	9.7	.56	4.39	.43	5.7	.65	6.03	.34
Aspirations ...	7.9 } 17.6	.49	3.10	.24 } .67	3.9 } 9.6	.63	5.67	.22 } .56
Filter*	(2.4)	(.70)	6.94	(.17)	6.5	.67	6.40	.42

Both Machines Throughs of 1st and 2nd Sheet to C Roll.
„ 3rd and 4th „ D „
Tails and Aspirations to 4th Break Scalper.
Filter to Offal.

* No measurements could be made on material carried away to Filter for "A" Machine. The figures in brackets are estimated.

† All weights are expressed as percentages of the feed.

Standard Purifier *versus* Special Tinless Purifier "D."

As above stated a further attempt was made to overcome the weakness of the tinless purifier by building machine D with narrow high velocity channels for carrying away the heavy liftings; that is to say, these high velocity channels were intended to perform, and in fact did perform, the same work as the tins. The results of the test on this machine are shown in Table V. It will be seen here that the throughs of all four sheets are just as good on the tinless machine as on the machine with tins, in fact a slightly higher percentage of throughs was obtained. As regards the total aspirations, almost exactly the same amount was lifted in the two cases. With the purifier with tins, the tins contained a fair amount of good material which was returned to the 4th break scalper. The chief difference was that machine D sent a very large amount of low quality material to the filter. On the whole there is not much difference in the work of the two machines. It is very difficult to say from the results which in fact is the better machine.

Conclusion.

We may summarise the results of the above tests as follows :—

1. As regards the commercial machines tested, the purifier with tins gave substantially better results than the tinless machine.
2. The tinless machine, however carefully designed, has an inherent defect; it is impossible to catch the heavier liftings, which therefore accumulate on the sieve,

and the work of the 3rd, and especially the 4th sheets, is inevitably much inferior to that of a standard machine fitted with tins.

3. By arranging specially high velocity aspirating channels to remove this excess matter, a tinless machine can be made to give results equal to a machine fitted with tins. There are, however, still two objections :—

   (*a*) That the cost of the machine is now as great as that of the purifier fitted with tins.

   (*b*) The machine fitted with tins aspirates the heavier liftings from the lighter liftings which go to the dust collector. This is a useful separation which cannot be made on the tinless machine.

Generally speaking, therefore, our tests forced us to the conclusion that the ordinary type of tinless machine must necessarily do inferior work to the machine with tins. The further attempts we have made to get over this difficulty have not been successful, and we conclude therefore that the standard machine fitted with tins is definitely better than any alternative that has yet been devised.

Chapter X.

AN ANALYSIS OF THE POWER REQUIRED TO DRIVE A FLOUR MILL.*

The standard power generally assumed for driving a complete flour mill, including intake plant, silo, warehouse, lighting, and all other loads that the engine may have to take is about 15 I.H.P. per sack. One hears, however, of millers who say that the total horse-power they require does not exceed 10 per sack, and of others who rather ruefully admit that they are using 18 or 19 I.H.P. The object of the investigation, the results of which are given in this paper, is to find out the reason for these variations, and whether the mill which takes the lowest power is necessarily the one which is best run and most likely to pay. Another object which has been kept in view is to find out what probable increase or decrease there will be in the power required to drive a mill if certain alterations are carried out in the machinery.

The only other similar tests of which I have been able to find any record is a series of tests carried out by Mr. Henry Simon about 25 years ago† on an 8-sack plant. The best method at that date of measuring the power was by taking indicator readings from a steam engine, which is, of course, much more laborious and less accurate than the methods at present available.

With one exception, to which I shall refer later, the results of our tests agree closely with the conclusions arrived at by my father, but owing to the superior methods available we have been able to

* This chapter is a paper, "An Analysis of the Power Required to Drive a Flour Mill," read by the author at the Convention of the National Association of British and Irish Millers, in 1913. The paper is reprinted exactly as read, except that throughout the costs have been re-calculated on the basis of 1925, and therefore represent approximately correct figures for to-day (1930).

† See Chapter XI.

go considerably further than he did. We also have valuable readings of the total power required both from steam and electrically-driven mills, which have enabled us to substantiate the various conclusions arrived at.

Unit of Power.

The first point we have to settle is the standard by which we are to measure our power. In the case of an average mill driven by ropes direct from the fly-wheel of the steam engine, the results by which the miller must be guided are the indicated horse-power of the engine. The efficiency of a good modern engine is generally about 90 per cent., or, in other words, the brake horse-power at the fly-wheel of the engine is 90 per cent. of the indicated horse-power. The efficiency of a good rope drive is about 95 per cent., and the efficiency of the shafting and the drives to the machines will average about 90 per cent.

Taking all this together, we find that the actual brake horse-power at the pulley of the roller mill, or other machine, is, in the case of a good average mill, 77 per cent. of the indicated horse-power.

As the great majority of mills are still driven by steam engines, I think it is desirable to take indicated horse-power as the standard of reference throughout this paper.

In order to arrive at the actual cost to the miller of any variation in the power consumed by the mill, figures are given in Table V. showing the average cost of 1 I.H.P. hour under varying conditions. The general average cost may be taken as .5 of a penny, and for convenience wherever calculations dealing with the cost of power are made in this paper I shall assume this

figure. A simple calculation can then easily be made showing how the cost would vary in the case of a mill where the price per I.H.P. hour is either higher or lower.

Method of Carrying Out Tests at Messrs. Vernon's.

The detailed tests on which this paper is mainly based were carried out by the kind permission of Messrs. Vernon in one of their Birkenhead mills. Observations on individual machines were made by driving each machine separately through an open belt by a motor temporarily secured to the floor in the most convenient position. An ammeter and a voltmeter were placed in circuit with this motor immediately in front of the brush leads, so that there would be no cable losses included. A specially designed variable high-speed motor was employed, and the speed was reduced through gears built into the motor frame. Careful calibration tests were made on the instruments themselves, and a special brake test was made on the motor under all conditions of speeds and loads. The brake was applied on the low speed shaft after the gears, so as to include any loss due to this cause. Curves were made from the calibration test showing the accuracy of the ammeter and voltmeter, and the efficiency of the motor itself under varying conditions, and the necessary corrections were made in all the observations made during the test.

Not only were these preliminary precautions taken, but during the tests themselves no readings were taken unless the instruments showed that the power was fairly steady, and that the machines were running under normal conditions. Power readings were taken immediately preceding meas-

urements of the feed with which they are connected, and immediately afterwards. Further, the instrument readings were checked by readings taken at the main switchboard from which the power was obtained.

The same care was taken in measurements of the speeds and the feeds, and I think it may safely be assumed that the experimental error was reduced to a minimum.

By the method above described, tests were made on all the different types of machines, as well as on elevators, worms and other conveyors. In the case of purifiers, only one machine was tested, as, firstly, the power taken was extremely small, and, secondly, there is no reason why one purifier should take substantially more power than another. As regards centrifugals and double horizontals, five or six machines were tested, as it was found that there was considerable variation between the power required for scalping various stocks and for dressing, though even in this case the power required by one machine does not, under normal conditions, exceed about 2¼ B.H.P.

As regards the roller mills, in view of the fact that nearly 70 per cent. of the power required in the mill itself is absorbed in these machines, a very large number of careful tests were made. These will be referred to in detail later on.

It should be explained that this mill is a centrifugal mill on the " Simon " system, the scalping being done on double horizontals. The only point in which it diverges seriously from the standard practice is that it is well known that Messrs. Vernon make a special point of high quality offals, and accordingly make a considerably lower yield of flour than is customary in this country.

In view of this, they are able to get first-class results with a much shorter roller surface than would otherwise be possible.

General Results of Tests at Messrs. Vernon's.

Table No. 1* gives an analysis of the power used in Messrs. Vernon's mill. The figures are based on actual tests of the brake horse-power required by the various types of machines and accessories. In each case, sufficient machines were tested to enable us to arrive at a safe average figure, and this was then multiplied by the number of machines, making due allowance for variations in the quantity and quality of feed, and variations in the speed of the machines. By this means, it was possible to get figures for all the machines, but in order to get by addition at the total figure which should represent the indicated horse-power of the engine, the following assumptions have been made :—

1. I have assumed that the combined efficiency of the line shafts and the drives from the line shafts to the machines is about 94 per cent. The whole of the line shafts are in first-class order and are not unduly long, and the drives to the machine are in every case good ; hence I have assumed this rather high figure, which in many mills would be reduced to, say, 90 per cent.
2. For the rope drive, which is again a good drive, I have assumed an efficiency of 95 per cent., which is a generally accepted figure.
3. For the engine, which is a fairly modern engine in good condition, an efficiency of 90 per cent. has been assumed.

* For Tables see end of Chapter.

It will be noticed that the various figures given in the table are shown in terms of indicated horse-power per sack, the rope race and engine efficiencies having already been allowed for.

On this basis, the table shows that the total power required by the mill should be 10.74 I.H.P. per sack. As a matter of fact, the actual indication of the engine under the conditions under which the mill was working during the trial, shows 10.5 I.H.P. per sack, thus affording a satisfactory test of the accuracy both of our actual readings and of the various assumptions detailed above.

Roller Mills.

Figure 41 summarises the results of a very large number of tests on different roller mills under varying conditions of feed. In all the curves the amount of power required to drive the roller mill without feed has been deducted. In each case the curve represents the power required by one pair of rolls only.

I may mention incidentally that we found, by tests on several 40 and 60-in. roller mills, that the average power required to drive a pair of rolls without feed may be taken at $\frac{1}{2}$ B.H.P., and that the difference between a 40-in. and 60-in. roll in this respect is negligible. We found that, if the machine is not in a first-class condition, this figure may be very much higher, amounting easily to 1 H.P. for a pair of 40-in. rolls.

The tests for breaks were made on 60-in. rolls and for reductions and bran on 40-in. $\times$ 10-in. rolls. The rolls were in each case originally tested as working under normal conditions—that is to say, set so as to give the best normal milling results. The feeds were then varied, and the rolls re-set

by the miller in charge, a very experienced man, so as to give as nearly as possible the same grind as before. In practice it was found that, throughout the range of feed covered by the tests, the rolls could be set so as to liberate practically the same percentage of flour. It is not of course contended

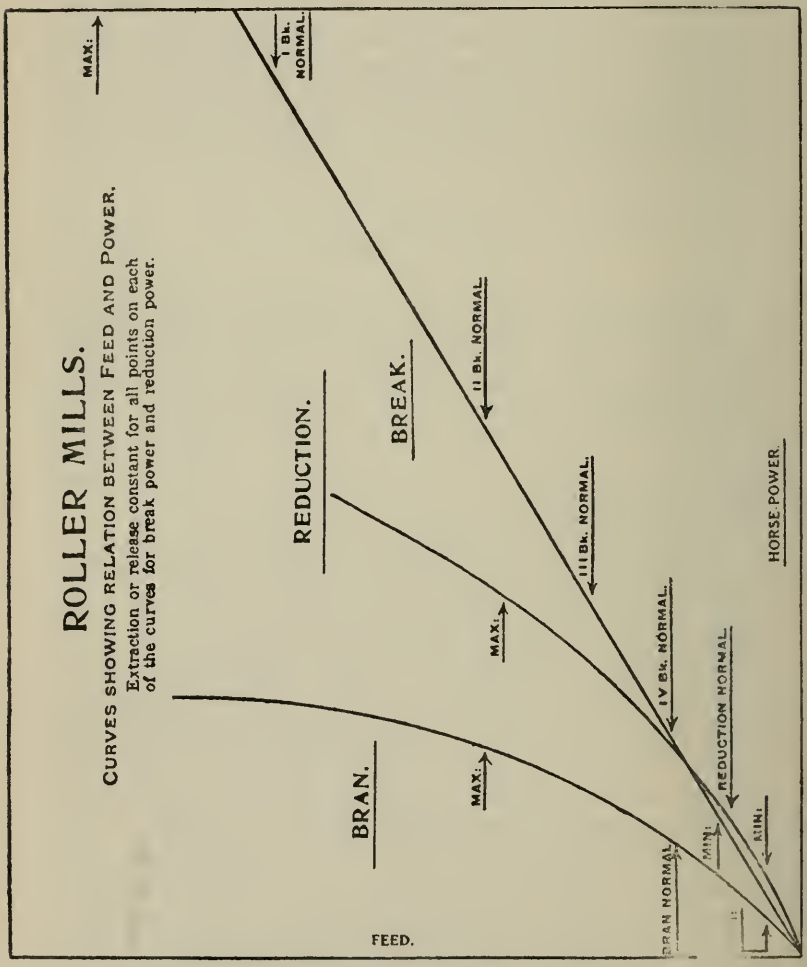


FIG. 41.

that the products were exactly the same throughout all the tests, as it is well known that the milling results deteriorate when the rolls are too heavily fed.

It will be seen that, in the case of **break roller mills**, the curve showing the relation between the power to drive the roll and the feed on the roll is practically a straight line; that is to say, the power is proportional to the total feed, or in other words, the power per lb. of feed is constant irrespective of the thickness of the feed on the roller mill. I have already explained that the power to run the mill empty was deducted before this curve was drawn, so that to get the total power on any given feed, this amount of roughly $\frac{1}{2}$ H.P. must be added to the power given by the curve. If we make the assumption that the total power required is proportionate to the surface when the feed per inch is constant, we can deduce a general formula as to the total power required by the break roller mills in the mill :—

$$P = AF + BN$$

Where P = the total power required,
F = the total feed to the whole of the break roller mills,
N = the number of machines.
A and B are constants.

This formula is not quite correct, as there is some variation between the power required on the different breaks, which will depend entirely on the way the rolls are set. Under ordinary conditions in a 4-break centrifugal mill the power required by the first break is considerably greater than that required by any of the other breaks, whose requirements are roughly equal. The formula given above may, however, be taken as a fair approximation to facts in an average mill.

It will be noticed, in the case of **reduction roller mills**, that the curve is of quite a different shape from that of the break roller mills. From this curve we see that as the feed increases the power also increases, the quality of the work remaining constant, but the power does not increase as rapidly as the feed; in other words, the power per lb. of feed is less with a heavy feed than with a light one. The relation between the feed and the power for the whole of the reduction system can be approximately expressed by the equation :—

$$P = D \sqrt{SF} + BN$$

Where P = total power for driving the reduction roller mills,
F = the feed to the whole of the reduction rolls,
N = the number of reduction roller mills.
S = the reduction roll surface.
D and B are constants.

This is the only one of the results obtained by the present series of tests, which is different from the conclusions arrived at as a result of the tests made by my father 25 years ago. In view of this fact, very special attention was given to these tests, and the curve shown to you is the mean of a large number of different curves, each of which is the result of six or more tests. The roll was in each case carefully set by the miller in charge so as to give the same percentage of flour, and his results were also checked by sieving tests, which absolutely confirmed his setting of the rolls. The whole matter was gone into with the greatest care, and I am confident that the results now given are substantially correct.

It must be remembered that Mr. Henry Simon's tests were made by indicating a small engine,

essentially a somewhat inaccurate and slow method, and that, as regards reduction rolls, comparatively few readings altogether are given. The discrepancy may, however, be explained by the fact that, as is well known, roller surfaces were very much shorter in those days than now. Mr. Simon does not state in his paper, nor have we been able to find records to show, what feeds he considered the normal and what he considered an overload. It is possible, if not probable, that what he considered a normal feed in those days would be considered a rather heavy feed nowadays, and that what he gives in his paper as a heavy feed is a feed very much heavier than anything we have tested. In most of our tests, the maximum feed was under 1,000 lbs. per hour for one pair of 40-in. rolls. If a very much heavier feed than this were put on and the rolls jammed up to try and get a result which, in fact, cannot be obtained, the power might well go up out of all proportion; but sweating would immediately begin and anything like satisfactory work would be impossible. The whole of our tests were carried out with the roll running under fairly normal conditions in the mill, and, though we overloaded many of the rolls, we only overloaded them about to the point at which they could still give acceptable results.

The third curve gives the results obtained by the testing of **bran rolls.** It should be explained that these rolls were working without any differential, and it will be seen that after a certain point the lines become vertical, *i.e.*, an increase of feed does not mean any increase of power. This is easily explained, as the additional feed simply acts as a cushion between the two rolls, and is not sufficient to cause any increase in pressure, and therefore any friction on the bearings. Satisfac-

tory work is impossible above the point in the curve marked " maximum."

Deductions with Regard to Roller Mill Powers.

Now that we have arrived at definite formulae for the power required for break and reduction rolls respectively, we can easily make various deductions as to the total power required for the roller mills in a mill under various conditions. The formula for the breaks $P = AF + BN$ shows that the power is independent of the total roller surface and that it consists of two factors ; firstly there is about $\frac{1}{2}$ H.P. for each roll, and secondly there is an amount of power proportional to the total feed for the whole of the roller mills.

Now it is clear that with a 6-break system the sum of the feeds to all the break roller mills would be greater than with a 4-break system. The number of machines will also be greater, so that a 6-break system will certainly take more power than a 4-break system. It is also clear that it is quite possible to reconstruct a mill giving increased break surface and yet reducing the total power required. Suppose, for instance, that a mill had two 24 in. by 10 in. four-roller mills on each of four breaks, and that these were thrown out and replaced by one 60-in. four-roller mill in each break. The surface would be increased from 384 to 480 inches, but the power, which is unaffected by the increase of surface, would be actually decreased by 4 H.P., owing to the smaller number of machines. Another interesting point is that if the break system is overloaded, though there will, of course, be an increase in the total power required, the increase will not be quite proportional to the increased feed, so that the power per sack will be reduced.

This last statement also applies to reductions, though not to quite the same extent, and it is also true for the reductions that the smaller the number of machines for a given surface the less the power required. On the other hand, we can no longer say that an increased surface, as in the case of breaks, does not mean an increase in power. With a given feed the power per sack does not increase in proportion to the additional surface, but it does increase roughly in the same proportion as the square roots of the surfaces. That is to say, in reconstructing a mill and extending the reduction surface, keeping the capacity constant, although generally speaking there would be big advantages in milling, some increase in power must be looked for, except in very exceptional cases where the surface is slightly increased, and a number of small rolls are displaced by fewer larger ones.

It is very difficult, in the case of actual reconstructions of mills, to account accurately for the variations in power after the reconstruction, but as far as we have been able to check the results in actual practice of mills we have reconstructed during the last few years, they agree with the conclusions here stated.

Dressing Machinery.

It will be noticed that the power taken by the dressing machines in this mill is just about one-sixth of the total mill power. The chief point of interest in connection with these machines is the saving which can be effected in a plansifter mill as against a mill where the whole of the work is carried out on centrifugals and double horizontals. It is sometimes claimed that the saving so effected is an item of the greatest importance, and

itself justifies the adoption of plansifters as against centrifugals. I have accordingly worked out carefully what the maximum possible saving would be by the substitution of plansifters for centrifugals in the 55-sack plant where the tests were made. It will be noted that in this mill the power required for driving the centrifugals and scalpers is 1.169 I.H.P. per sack, or a total of 64.3 I.H.P. Let us assume that the whole of this work could be done on 30 plansifters, which is the smallest number of standard-sized plansifters which could be got to do the work satisfactorily. Let us assume also that each sifter requires only ½ I.H.P. to drive it. This is equivalent to about 0.38 B.H.P. per machine, and is certainly on the low side. On this assumption the total power required by the plansifters would be 15 I.H.P., or a saving of 49.3 I.H.P. as against the present conditions. At 0.5d. per H.P. hour this is a saving of just 24.7d. per hour, or, assuming the mill runs 6,600 hours in the year, £680 per annum.

On these figures I think it is perfectly safe to say that the maximum possible saving in a good 55-sack plant, where the cost of power is 0.5d. per indicated H.P. hour by the substitution of plansifters for centrifugals and double horizontals, is £680 per annum. This is, of course, an important item which must be borne in mind in considering the relative advantages of plansifters and centrifugals, but it is clearly not enough in itself to be the determining factor on so difficult and controversial a point.

Purifiers.

Where double dustless purifiers are used, even when each separate purifier is connected to a pressure filter, the power required is small. The

modern system of connecting all the purifiers together has, however, caused a considerable increase in power. Table II gives particulars of the power required per sack for the different systems of purifier exhaust all taken from actual instances in different mills. It will be noticed that suction filters may require something like double the power required by pressure filters.

It should, however, be pointed out that the tests on the suction filters were carried out with an old type of machine, and that there are now suction filters on the market which offer very much less resistance to the passage of air. The total powers given in the paper as necessary for a system of purification connected with suction filters can accordingly be considerably reduced in the most modern installations.

Another interesting point brought out by the Table is the difference between the system, generally adopted in England, of large exhaust trunks creeper cleaned, as against the system, commonly adopted in America, of small trunks where the air has such a high velocity that the air itself keeps the trunks clean. It will be seen that considerably more power is required in the latter case, to the extent of something like 0.2 I.H.P. per sack.

Worms and Elevators.

It will be noticed that the total power required by the worms and elevators in Messrs. Vernon's mill, taking the mill only, is just under 0.4 I.H.P. per sack, the power for the same purpose in the wheat cleaning being about 0.25 I.H.P., the total power required for all the conveyors being about 0.65 I.H.P. In this case we are able to make a comparison with another large mill, which is very

crowded and where an abnormally large number of conveyors are required. A special elaborate series of tests was made to find out whether or not there was an undue waste of power due to the conveyors in this mill, and the total power came out at something over 1.5 I.H.P. per sack. I think these two figures may be taken as representing about the limits between which the power for this purpose would vary.

Range of Power for Mill Alone.

I have now dealt with the main points in the mill proper which are likely to account for variation in the power. It is possible, from these figures, to say what is the lowest and what is the highest power that ought to be taken by the actual roller mill plant.

Table III gives a comparison between two imaginary mills. The high-power mill may be taken as representing the maximum power which should be taken by a well-run mill of at least 20 sacks per hour capacity. The power increases with smaller mills, so that it would not be impossible to have a well-run mill of, say, five sacks an hour taking considerably more power than that given here as the maximum for a high-power large mill.

In the case of the low-power mill, I have practically taken Messrs. Vernon's figures, allowing a liberal reduction for plansifters. We have also included, in this case only, the power taken by the actual milling machines, omitting offal grinding and bran rolling, which I have included in the other case.

The figures in the high-power mill, which come out at considerably more than double the power required in the other case, are all based on figures

actually obtained in different mills, and in every case are for efficiently run and well looked after mills. The break roll powers are high, owing to the fact that there are six breaks, the reduction powers owing to the fact that there is a complicated reduction system, and that a long yield is made. The scalpers are about the normal power for a centrifugal mill, and the purifiers are assumed to be all coupled together to a suction dust collector. It is also assumed that a suction dust collector is used on the exhaust from the rolls and centrifugals accounting for an extra $\frac{1}{4}$ H.P.

As a matter of fact, these figures are not in all cases extremes, as we know of one first-class mill where the reductions are actually taking only slightly over 4 H.P. per sack.

Comparison of the Power Required by Various Actual Mills.

Table IV gives an analysis of the power actually required to drive seven typical mills. The mills were selected firstly because I happened to have the necessary data in some cases, then because they are all good modern mills, and because they illustrate well the variations which occur in the consumption of power in the different departments. As regards sizes, A is over 50 sacks an hour, B, C, D, E and F all vary from 15 to 25 sacks an hour. They are all centrifugal mills, though there are a few plansifters working in some of them.

As regards the power consumed by the actual mills, it will be seen that the average for a 20-sack plant may be taken as just about 10 I.H.P. per sack. It will be noticed that Mill " B " takes no less than 13.2 H.P. per sack. This is due largely

to the fact that it was built as a 20-sack plant with the intention of future extension, that there is an unduly large number of elevators and conveyors, and that many of the machines which will be required for the larger output are already at work. In addition to this, the mill produces specially fine flour, using No. 13 silk even on "A" reduction. There can be no doubt that this means a considerable increase in power.

"A" Mill, being a large mill, ought, undoubtedly, to take a lower power, but in this case the power is high owing to the roller surface being no less than 117 ins. per sack, and to the fact that the mill is crowded and not of the best modern design, which means an excessive number of conveyors and some rather unsatisfactory drives.

Vernon's mill takes by far the least power of any of those given in the table, owing, firstly, to its size, secondly, to the excellence of the arrangement, and thirdly, to the fact that they make a short yield.

As regards **the screen room,** one point which is clearly brought out by the figures is that there is a tendency for a higher power to be required in this department in the case of a small mill than in a large one, though this does not apply to the same extent in the roller mill plant itself. This is due to the fact that many of the machines in the screen room take a good deal of power to run empty, and not very much more power when the feed is on. This applies to washers, separators, cockle and barley cylinders. The result is that, unless these machines can be heavily fed, as is the case in a large mill, the power required per sack is increased.

Another point of interest is brought out by tests in a mill where the wheat cleaning has a

capacity of about 20 qrs. an hour. The full power taken is 2.14 H.P. per sack, and the power to run the wheat cleaning empty is no less than 1.69 I.H.P. per sack; that is to say, the extra power due to the wheat itself is only 0.45 H.P. per sack.

The fact that "D," a 16-sack plant, takes 3.2 H.P. for the wheat cleaning, whereas "E," which has practically the same capacity, only takes 1.36 H.P., is sufficient proof that it is impossible to generalise as to the power taken by wheat cleaning plants. In the cases of E and F, quite an exceptional amount of attention has been given to the question of the amount of power. Various steps have been taken to reduce it, by the elimination of certain machines and especially by very successful attempts to minimise the amount of air required in the exhausts without decreasing the efficiency of the exhausts.

As regards **bran rolling and offal grinding,** it will be noticed that the power varies from 0 up to 1.1 H.P. per sack in one case and 1.0 in the other, giving a good illustration of the different practices of different millers in these respects.

As to the remainder of the power, this consists mainly of the power to drive intake plant, silo, and warehouse. An interesting comparison is afforded in this case between Messrs. Vernon's, who only use 0.8 H.P. per sack for all their extra drives, including lighting, etc., and mill "A" which uses 4 I.H.P. for this purpose. Messrs. Vernon have special arrangements rendering it unnecessary for them to use power for these purposes, whereas mill "A" has a very complete plant, including its own ship elevator for working cargoes, a complete granary, and a warehouse fitted throughout with the latest labour-saving

devices. I know the mill well, and am quite certain that the 4 H.P. used for these purposes represents a good investment, and that any attempt to reduce this power would simply mean a large additional expense in the form of extra labour.

It must be borne in mind, in considering these figures for auxiliary plant, that silo machinery is generally only working a few hours in the day and the warehouse probably 12 hours; so that in this case the total of 4 H.P. will, on the average, be working at something less than half the time that the mill is working.

Common Causes of Waste of Power.

The chief ways in which power may be wasted are three, *viz.*, the transmission of power, the conveying of products, and bad grinding. As regards transmission, this is a matter which it is very difficult to determine by any test. I have already shown that in a really good mill the brake horse-power at the pulley of the machine is only about 77 per cent. of the indicated horse-power of the engine. There is no doubt that with bad drives this must be considerably less, but it is very difficult to give any estimate as to what the loss may be in this direction.

In this connection it is of interest to consider whether any economy can be made by electrical driving, either by driving individual shafts by motors, or by going even further and having separate motors for the machines, as is to-day a common practice, for instance, in weaving sheds.

Careful consideration of the various actual examples shows that it is impossible, by having separate motors to each shaft, to get an efficiency higher than can be got in a good steam-driven

mill, and that the cost of supplying separate motors to each machine is prohibitive. It is only when a steam-driven mill has really bad drives, so that the efficiency falls from 77 per cent. to 70 per cent., or even 60 per cent., that the substitution of electrical motors is worth considering.

The outlying drives, such as warehouse and silo, are nowadays almost invariably electrically driven, though there are cases where the power may be efficiently transmitted by shafts or ropes, and other cases where serious waste is caused by bad drives to these departments.

As regards the conveying of products, this is undoubtedly a common cause of wasted power in a mill. I have already shown that this may vary from 0.6 indicated horse-power per sack up to 1.5, a total waste in that case of 0.9 H.P. per sack.

With reference to grinding, some very interesting figures were given in my father's paper to show the extraordinary amount of power that may be wasted by having blunt break rolls, or by having either break or reduction rolls badly set. As the roller mills take anything from 4 to 6 I.H.P. per sack when well set, it is quite clear that this is a potential source of very serious waste.

5.7 or 8.5 Horse-power per Sack?

One point to which I should like to draw attention is the need for special care in interpreting what is meant when a miller says that his mill requires so many horse-power per sack to drive it. To illustrate this I will take the case of Messrs. Vernon's, of which I have already given details. The total indicated horse-power to drive Messrs. Vernon's mill is 10.7. The indicated horse-power required to drive the mill and wheat cleaning is 9.9. If, however, we want to get at

the actual figure, for the mill alone, which may be comparable with other mills, we are clearly justified in deducting the bran rolling and offal grinding, and in saying that the power required to drive the mill itself is 7 I.H.P. If, now, we choose to express this in terms of brake horse-power at the pulley in the line shaft, we find that the power required by the machines is just under 6 H.P. per sack; and if we go a step further, and measure the power at the actual pulleys of the machines and accessories, it comes down to the extraordinarily low figure of 5.6 per sack. It is accordingly correct to say,in one sense, that the power required by the mill alone is 5.6 H.P. per sack. On the other hand, it is equally true to say that the power required (including bran rolling and offal grinding) is 8.5 H.P. per sack. Even in the higher figure, the power for the lighting of the mill is excluded.

Omissions.

There are many interesting points in connection with the power required to drive a flour mill which I have been unable to deal with in the time at my disposal.

With regard to engineering matters, I have been compelled to omit all reference to the various methods of lubrication and to the use of ball or roller-bearings, or to variations in the speeds of the rolls or other machines.

As regards milling points, I have only just touched on the question of the effect of yield and of fineness of dressing, and the effect of the size of the mill on power.

A very interesting question is the effect of the condition and quality of the wheat itself on the power required in a given mill, and I regret that it has not been possible to deal with this.

Conclusions.

I have already shown that with two well-run mills the power required for the mill itself may vary from say, 7 to 14 H.P. In this very extreme case, the extra power taken by the high-power mill is 7 H.P., which at 0.5d. per H.P., means an extra charge of 3.5d. per sack. This is, of course, in these keenly competitive days, a serious item, but it must be remembered that, in return for this, the high-power mill has much greater roller surfaces and a better purification system, as well as an elaborate system of bran rolling and offal grinding, to mention only a few of the more important advantages. In certain cases, the extra advantages of a higher power mill may make a difference of several times 3.5d. per sack.

The chief conclusion to which I am driven is that the total indicated horse-power per sack used by a mill is no guide whatever to anything. A mill using 18 to 19 horse-power per sack may be working on the most efficient possible lines, whereas one using 12 indicated horse-power per sack may have bad drives or an undue number of conveyors, or may otherwise be working inefficiently. Another point, which is clearly brought out, is that the cost of the power consumed by any alteration in a mill is generally a relatively unimportant item compared with any effect which such an alteration may have on the quality of the products, or on the ease of working of the mill. At the same time, any additional use of power does mean a definite annual expense, and I hope that the facts and figures given in this paper may be of some assistance to millers, both in finding out where they are using any unnecessary power, and in estimating the probable cost of extra power for any proposed alterations.

Table I.

Analysis of Power Required to Drive Messrs. Vernon's Mill.

Allowing 0.9 for engine efficiency.
Allowing 0.95 for rope race.

Mill.	I.H.P. per sack.	
Break roller mills	2.5	
Reduction roller mills	2.04	
Scalpers	0.249	
Centrifugals	0.92	
Purifiers (dustless)	0.232	
Exhaust fan	0.274	
Elevators	0.204	
Lineshafts in mill	0.392	
Worms in mill	0.192	
		7.0
Screens		1.41
Offal Grinding		0.42
Bran Rolling		1.11
Generator for Light, Warehouse, Barge Elevator, and Ovens		0.8
		10.74

Table II.

The Power Required to Drive Various Types of Purifier Systems.

Allowing 77 per cent. efficiency for the transmission from machine pulley to engine, including engine efficiency.

System.		I.H.P. per sack.
Filter.	Exhaust Trunk.	
Dustless purifiers with expansion chambers.		
No filters	No trunks.	0.232
Suction	Self cleaned.	2.15
Pressure	Self cleaned.	1.1
Suction	Creeper cleaned.	2.0
Pressure	Creeper cleaned.	0.91

Table III.

Comparison Between the Power Required to Drive the Actual Flour Milling Machinery in a Complicated and in a Simple Mill.

Machine.	High Power Mill I.H.P. per sack	Low Power Mill I.H.P. per sack
Break roller mills ...	3.0	2.5
Reduction roller mills ...	3.6	2.0
Scalping and dressing machinery	1.5	0.5
Purifiers	2.1	0.23
Elevators, line shafts and worms	0.8	0.8
Exhaust	0.5	0.27
Offal grinding	1.4	—
Bran rolling	1.1	—
Total	14.0	6.3

Table IV.

Analysis of the Total Powers Required in Various Typical Mills.

(The figures are I.H.P. per sack.)

Point of Application.	Atlantic Mills, Vernon's	A.	B.	C.	D.	E.	F.
Mill proper ...	7.0	9.31	13.2	8.88	9.73	10.6	10.23
Screen room	1.41	2.09	2.83	1.85	3.20	1.41	1.36
Bran rolling ...	1.11	0.65	—	0.45	0.83	0.35	0.33
Offal grinding	0.42	0.77	—	0.17	0.95	1.0	1.0
Silo or intake		1.71		1.49	1.18	0.81	0.87
Warehouse ...	—	1.29	—	1.17		—	—
Lighting, engine auxiliaries other than those direct coupled, electric ovens, pumps, etc.	0.8*	1.0	3.0	0.25	1.67†	0.27	0.34
Totals ...	10.7	16.82	19.03	14.26	17.56	14.44	14.12

* Includes Intake. † Includes Warehouse.

Table V.

The Total Cost of 1 i.h.p. per Hour for Varying Total Powers.

	Cost in Pence per I.H.P. per Hour.				
	160 I.H.P.	375 I.H.P.	700 I.H.P.	1050 I.H.P.	1400 I.H.P.
Capital*	0.12	0.093	0.080	0.063	0.06
Maintenance, oil, wages, repairs, etc.	0.20	0.117	0.095	0.077	0.065
Coal (at 20/- per ton)...	0.25	0.22	0.2	0.19	0.185
Total ...	0.57	0.432	0.375	0.33	0.31

* Interest and depreciation taken at 12½ % per annum. Buildings and foundations not included.

Chapter XI.

RECORD OF TESTS OF THE POWER CONSUMED BY VARIOUS MACHINES IN ROLLER FLOUR MILLS.*

By HENRY SIMON, M.Inst.C.E., M.I.Mech.E.—1887.

Before entering on the subject matter of the present paper, it may not be out of place or uninteresting to many of the millers present to refer to a former paper which I had the honour to read before the Millers' Association in this hall in the year 1879.

At that time roller milling was just beginning to excite general interest in this country, and your Association met to give me an opportunity of bringing the subject more prominently before them. The views that I then expressed on the advantages of roller milling were very freely criticised in the discussion which followed the paper, and one assertion amongst others was received with great incredulity, *viz.*, my statement that, in a comparatively small number of years, rollers would have almost entirely replaced stones in the manufacture of flour in this country.

The results of the few years that have passed have more than fulfilled the expectation I then expressed. Roller milling *has* replaced stone milling, and the millers who are assembled here to-day have, during those years, passed through an experience that qualifies them to act as excellent judges of the importance or otherwise of this the second subject, which it is my privilege to bring before your Association, *viz.* :—

* This paper by Mr. Henry Simon, father of the author, was read before the National Association of British and Irish Millers, in 1887, and is republished as a matter of historical interest. The results obtained in 1887 are almost entirely confirmed by those obtained in 1913. In the former case, it is necessary to add, the tests were made by the elaborate and difficult process of indicating the Horse Power of a steam engine; in 1913, the tests were made by direct drives from a motor and were, therefore, much easier to make, and are no doubt more reliable.

The Horse Power Absorbed in Roller Milling.

It is never very pleasant for an assemblage of business men to sit and listen to a paper which tells them nothing but what they know already, or repeats what has often been told and written before. In dealing, however, with the power absorbed in roller milling, this paper treats of a subject on which, as far as I have been able to ascertain, there is a general lack of published information; and while I do not profess in every instance to tell something entirely new, yet it does not repeat what has ever been published before, and deals exclusively with a prolonged series of special trials extending over a protracted period, and executed for me under the continued superintendence of Mr. W. Stringer, and for the accuracy of which I, therefore, can vouch.

In instituting these trials my intention was, by a a series of accurate tests, to come to a reliable decision as to the power taken by the different machines used in roller milling, when worked under varying conditions, and to determine what proportion was taken by each section of the roller system.

In carrying on my business as a milling engineer, I daily felt the want of this information, and during the past years had collected an extensive record of the powers taken by a number of plants which I have erected in the United Kingdom.

While the experience gained in this manner had enabled me to approximate very fairly the amount of power absorbed by any particular work, and any particular machine, I still thought it would be worth the expense and trouble of the trials if

I could establish a reliable standard of the power that the different classes of machinery used in roller mills should take, when worked under fair conditions.

After consultation with Mr. Michael Longridge, who, as chief engineer of the Boiler Insurance Company, Manchester, has exceptional experience in the indications of power, he undertook for me the engineering superintendence of these trials, and the taking and calculation of the engine indications; my principal miller, Mr. Stringer, being responsible for the general supervision of the milling, the setting of the rolls, and the regulation of the machines.

The Kirkdale Roller Mills, Liverpool, where the tests were made, is a compact, well-built, six-floored building, five floors of which are partially occupied by the roller mill, a first-class 8-sack plant on my system, having plenty of room and light; it was for this reason a place particularly suitable for the trials, which were carried out with one double cylinder high pressure engine (with cylinders $16\frac{1}{16}$ in. diameter, and stroke 2 ft. 9 in.), driving the whole plant; and a small $8\frac{7}{8}$ in. diameter single cylinder engine, 14 in. stroke, which was placed on one of the mill floors, and to which the different machines, the powers of which were to be tested, were consecutively connected. The smaller engine was very sensitive and capable of showing the slightest variation in power.

During the trials, indications were taken with the large engine, while the mill was running under widely varying conditions, as the class of wheat, quantity of feed, and speeds of the machines, were changed successively.

With the large engine, the mill was also indicated in sections, and the power consumed by each

section was again and again checked, machine by machine, by means of the smaller engine, with which were also tested independently the elevators, worms, etc.

Indications were taken of the same machines under different conditions of speed, pressure used in grinding, etc., and a sufficient number of diagrams were taken to guard against error, in many cases several days being spent over one series of indications in order that a thoroughly reliable result might be arrived at. All indications, whether with the larger or smaller engine, were, whenever practicable, checked independently, and every precaution was taken that the results obtained should be not only approximately, but, as far as possible, absolutely correct.

It would be impossible, in the limits of a short paper, to go into the details of those trials, though to many the particulars would be interesting; but as the taking of the indications, with the preparations for them, and the necessary calculations afterwards was the work of months, it will be seen that only a very condensed summary of the results can now be brought before you.

Granulation.

I shall deal first with the granulation, giving only such results as I think will be interesting to the general miller, and omitting small fractions, except where the smallness of the total consumed power makes them absolutely necessary.

The quantity of wheat that was on the mill during the trials, of course, varied somewhat from day to day. In order to simplify the figures, I have by calculation averaged the work to $8\frac{1}{2}$ sacks (of 280 lbs.) finished flour per hour, and the results given are based on this quantity.

The mill was fitted up with six breaks, one pair of 24 in. by 10 in. fluted rolls being used for each break, the flutes of all being in good condition at the time of the indications.

With a full feed of medium condition wheat, and when thoroughly cleaning the bran, the different break rolls took as follows :—

First break, 2.0 H.P. ; second break, 4.12 H.P. ;

Third break, 3.45 H.P. ; fourth break, 3.45 H.P. ;

Fifth break, 3.0 H.P. ; sixth break, 1.32 H.P.

It will be seen that the greatest power was absorbed by the second break, and the least by the sixth, while the next smallest power was required for the first. Of this total power, 3.30 H.P. was required to drive empty the six pairs of rolls, and the balance of 14.04 H.P. was absorbed in doing the work.

With the mill on hard frosted Minnesota wheat, it was found that the breaks took 21 per cent. more power. This test had to depend on one set of indications, and could not be checked independently, so that I can only give this as approximately correct.

The speed at which a break roll would require the least power was carefully ascertained, and the results showed that any excess of speed was a distinct waste of power, without any counterbalancing advantage in the quality of the work.

It was also found that, when the rolls were sharp, there was neither gain in power nor improvement in the working effected by increasing the length of rolls on any of the breaks beyond a certain number of lineal inches per sack of flour per hour on each break.

The scalping of the full feed, when the six breaks were running, required 4.93 H.P., and of this 1.6 H.P. was absorbed in running the machine empty,

the balance of 3.33 H.P. being all that was required for the actual treatment of the feed.

Some of the breaks having been scalped in centrifugals and some in reels, another series of tests was made to determine the relative power taken by the two classes of machines.

When running idle, a double centrifugal scalper, three sheets long, used for the scalping of two breaks, took 0.55 H.P., while two four-sheet reels took 0.38 H.P., showing that more power was required for the empty double centrifugal than for the two empty reels.

A number of indications were also taken of the relative power absorbed in scalping. Thirty cwt. of wheat was passed through a one-sheet centrifugal scalper, and the power required for the scalping alone (not including that taken by the machine itself) was 0.82 H.P., while the same weight of feed in a four-sheet reel only took 0.51 H.P., proving that in the actual work of scalping or dressing a reel is more economical than a centrifugal scalper.

Smooth Rolls.

In the mill were four sets of 20 in. by 10 in., and three sets of 20 in. by 9 in. three-high smooth roller mills. These were found to take in the aggregate 22.46 H.P. or 2.64 per sack of flour; of this, 7.52 H.P. was taken by the machines running empty.

Two 20 in. by 10 in. mills treated all the first-class semolina and absorbed 6.74 H.P. One similar set of rolls and one set of 20 in. by 9 in. treated all the fine middlings, and absorbed 5.46 H.P., while one set of 20 in. by 10 in. and two sets of 20 in. by 9 in. treated the returns from the first centrifugals and all the second-class material and tails, and absorbed 10.26 H.P.

A trial of hard frosted Minnesota wheat showed the smooth rolls taking 4.70 H.P. per sack of flour, while the same quantity of medium wheat only took 2.91 H.P. Thus the power required when working on the hard wheat was 78 per cent. more than in the second case ; the *actual increase* of pressure on the smooth rolls, however, was very much greater, for if we deduct the power required to drive the empty rolls, the power absorbed in the actual grinding of the middlings was 112 per cent. more than was required for those from the softer wheats.

The power required to grind respectively light and heavy feeds was exhaustively tested, and the result conclusively proved that a very great deal of power can be wasted by overloading, or even by fully loading smooth roller mills.

In one case, a feed of coarse semolina on both pairs of a three-high mill was indicated, and absorbed for the grinding 3.36 H.P. When this *same* feed was put on one pair of rolls only it absorbed 5.93 H.P., or an *increase* of 77 per cent. to produce the same effect. This quantity was a *fair* feed for both pairs of rolls, but when put on one pair was a *very heavy feed.*

Taking again another mill running with a light feed, *both* pairs took 2.54 H.P., while the same quantity on one pair took 3.0 H.P., or an increase of 18 per cent. In this case the feed was, as just stated, a *light one* when divided over both pairs, and was what would be called a full feed for the single pair.

Another three-high mill had a *very light feed,* which took 0.57 H.P. Another mill had about double that quantity, but still was not what is usually regarded as overfed, yet the grinding took 2.81 H.P.

In all cases the material was better ground when spread over the larger surface, so that a small feed on a smooth roller mill will not only take relatively less power than a larger one, but the work at the same time will be more satisfactory.

The maintaining of the differential speed between rolls is generally secured by gear, but in some machines belts only are used. Considering that it would be advantageous to test the relative power absorbed by the different methods, a series of trials was carried out, and the results are very instructive.

In the first instance, a *fully fed pair* of rolls with gear were indicated, and absorbed 2.73 H.P. for roll and grinding. The gear was then taken off, and the two rolls driven independently by belts. Now, in putting on the necessary grinding pressure, the fast drive belt began to slip, and both rolls practically ran at the slower speed, the result being that only a small portion of the material was sufficiently ground, while the power absorbed was 2.90 H.P.

The fast roll belt was then thrown off, and the roll entirely driven by friction off the slow roll. The relief given by throwing off the slipping belt enabled the same amount of work to be done with 20 per cent. less power, the roll now working with 2.32 H.P. instead of 2.90 H.P.

A stronger belt was then put on the fast roll, and immediately the *slow* roll belt began to slip, and both rolls ran at the *quicker* speed. The quality of work was the same, while the power taken was increased to 5.63 H.P.

The *slow roll* belt was next thrown off, and the springs of the rollers were tightened, so as to put an increased pressure on the material, but the work was still as unsatisfactory, the middlings being only partially reduced, while 7.6 H.P. was absorbed.

Both belts were next strengthened, and with some difficulty tightened sufficiently to maintain the differential speed without slipping. The middlings were now ground sufficiently, but the power absorbed was 5.15 H.P., while with the gear for exactly the same amount of material it had only been 2.73 H.P.

These trials showed the great difficulty of maintaining, by belt, the exact differential speed when there is a *full feed* on the smooth rolls, and also established the fact that, when the differential speed is *not* maintained, there is a very great loss of power, apart from the bad quality of the work.

Continuing the trials with belt-driven rolls, it was found that with *lighter feeds* there is much less tendency for the belts to slip, and that where the work is sufficiently light to allow of fairly slack belts maintaining the differential speed, the horse-power absorbed is practically the same as with gear.

A further set of trials established that in a geared mill less horse-power is required if first transmitted to the quick running roll, the indication showing that with the driving belt on the *fast* roll the power required was 2.73 H.P., while with the *slow* roll drive it was 2.8 H.P., or an increase of $2\frac{1}{2}$ %.

Dressing Machines.

In dressing the material from the reduction rolls, eight centrifugals were employed, four $2\frac{1}{2}$ and four 3 sheets long. When running idle, these machines took in the aggregate 4.73 H.P., while with the feed they took 5.98 H.P.

Taking the entire dressing and scalping machinery in the mill, consisting of twelve centrifugals

and five reels, the power absorbed in running them empty was 7.96 H.P. while when dressing the 8½ sacks of flour it was 14.28 H.P. Of this, 8.30 H.P. was used for scalping and dressing the break meal and the material from the breaks, while the balance was required, as we have seen, for the dressing machines following the reduction rolls, the entire scalping and dressing taking 21½ per cent. of the total power required for the mill. That this power could be very much reduced was proved by repeated experiments, several machines being run considerably below their normal speed, the result being in every case that much less horse-power was required to do the same amount of work.

In one case, a particular machine, which had on it a very large feed, when running at 200 revolutions absorbed 1.43 H.P. for the machine and work, while the same machine at 160 revolutions only took 1.07 H.P.—a saving of power of 25 per cent.

Again, a centrifugal, scalping one of the breaks, took at 200 revolutions 1.56, while at 130 revolutions it only absorbed 1.15 H.P.—a saving of 26 per cent. In both these cases the work at the slower speed was as well done as at 200 revolutions.

On the further testing of the power taken by one of the 3-metre centrifugals, a single machine running empty at 200 revolutions was found to average 0.71 H.P., which was divided amongst the several parts as follows : The centre, shaft, and beaters, 0.51 H.P. ; the outside cylinder and rails carrying the silk, 0.12 H.P. ; and the collecting worm, 0.08 H.P.

Purification.

All the machines for purification absorbed the small power of 4.66 H.P.

Three semolina purifiers ran at 450 revolutions, and their fans at 900 revolutions. Under the purifiers were nine collecting worms, driven with cross-shaft and bevel gear. The three purifiers, fans, collecting worms, etc., only absorbed 2.55 H.P. or 0.85 H.P. per machine.

A " Reform " purifier, running at 450 revolutions, fitted with filter and a quick running fan, took 1 H.P. ; and two tailing sieves, an exhaust fan, and a dust catcher absorbed 1.11 H.P.

From the small amount of power which is taken by properly constructed purifiers, etc., it can be clearly seen that the better class of mill plants should require less horse-power per sack of flour manufactured than one on an inferior system. There is no other class of machines that with so little power will separate the injurious material ready for sending direct to the offal sack. The rejecting of similar material, in the absence of purifiers, by smooth rolls and centrifugals, etc., in addition to injuring the quality of the flour, must, and decidedly does, take considerably increased power.

There were, in this mill, 16 elevators running from the top of the mill to the bottom, each 48 feet high, all fair-sized elevators, with $4\frac{1}{2}$ in. cans, and $5\frac{1}{2}$ in. webbing. The whole power required to drive them empty at their full speed was only 0.65 H.P., and when the full feed was on the mill, the additional power absorbed was 0.69 H.P., the whole power required for the elevators at their full feed thus being 1.34 H.P.

To convey the material from the smooth rolls to the elevators and collect the flour and offals, 316 feet of worming was employed, which, running empty, absorbed 1.64 H.P. With the full feed on, the additional power required was only 0.48 H.P.

A special test of a large 9 in. worm, 47 feet long, carrying 24 sacks of flour per hour, gave 0.58 as the power absorbed by worm and feed.

Summary.

Briefly summarising the results given above, we find that, when grinding a medium mixture of wheat and packing 8½ sacks of flour per hour, the total power absorbed by the entire plant (exclusive of the friction of the engine) is 66.31 H.P.

Of this total the break rolls took 17.34 H.P., or 26.15 per cent. of the whole;

The smooth rolls 22.46 H.P., or 33.87 per cent.;

The scalping and dressing machinery 14.28 H.P. or 21.53 per cent;

The purifying machinery 4.66 H.P., or 7.02 per cent.;

The shafting 4.11 H.P., or 6.19 per cent.

The balance, 3.46 H.P., or 5.22 per cent., was absorbed by the worms and elevators;

The whole plant absorbed 7.8 H.P. per sack of flour manufactured.

Three-fifths of the total power was required on the roller floor, the breaks, as we have seen, taking more than one-fourth. This was with the rolls in *good condition*. During the earlier part of the trials, however, some of the rolls were dull, and required refluting. A comparison of the relative powers taken by them when blunt and when in proper order for working is very striking.

Not taking into account the power required to drive the empty rolls, which was the same in both cases, the fourth break, in a six-break plant, took with the blunt roll 6.8 H.P.,

while with the sharp roll it took only 2.9 H.P.
The fifth break roll (not quite so blunt) 3.22 H.P., sharp, 2.45 H.P. ;
The sixth break roll, blunt, 3 H.P., sharp, 0.77 H.P. ; or the three breaks took in the aggregate, when blunt, over 100 per cent. more power than they did when fairly sharp.

When it is remembered that the expenditure of this increased pressure was employed in producing heat, injured bearings, and general discomfort, it will be seen how very important a matter is the keeping of the break rolls sharp and in good condition for working. But it is not only in the waste of power, but more especially in the injury to the material, that *rounded corrugations* are most harmful.

The smooth rolls took one-third of the whole power. Deducting the friction of the rolls when running empty, the power absorbed in pressure was only 14.94 H.P., or almost exactly the same as the pressure on the breaks ; this will probably be thought extraordinary, but it is not ; it is simply the result of careful grinding.

One of the most widely prevalent fallacies in connection with flour manufacture is that it is easy to grind properly with smooth rolls. There is nothing in practical roller milling that requires so much skill and judgment ; and a really good grinder is rarely to be met with. It is not difficult to granulate, to purify or to dress properly, if the miller is provided with the right machines and has the proper system, but to grind on the smooth rolls, so that the work is done at its very best, requires more skill than the average practical miller possesses ; and as a consequence rolls sweat, journals wear out, gear makes a noise, and power is wasted.

Well constructed smooth roller mills, *properly set*, will grind the middlings from any wheat, hard or soft, without sweating; and an exhaust to a smooth roller mill is never necessary, except to reduce the troublesome effects of bad work.

Too much pressure, badly fitted or too tight scrapers, or uneven setting, are the most usual causes of wasted power. To give an instance of over-pressure :—

A roller mill with a certain feed was set too closely, that is, when the material was being properly ground, more pressure was put upon it. After a few minutes the machine began to sweat, and gradually, through some of the material sticking to the roll, the power became higher; the pressure was again increased, and eventually the roll was indicated, showing that 6.19 H.P. was being absorbed.

The pressure was then reduced, the roll cleaned itself, the sweating gradually disappeared, and though the grinding was quite as close as before, the power required was only 2.87 H.P., or less than one-half.

The work on the roller floor has supplied the material for most of this paper, principally because the power consumed on it is so much under the *control of the miller*. All the rest of the machinery of the mill took only 26.49 H.P. in an $8\frac{1}{2}$ sack plant, so that the importance of attention to the rolls is self-evident, if power is to be saved in a roller mill.

Lubrication.

One of the most striking and instructive facts demonstrated during the trials was the paramount importance of having all bearings sufficiently and continually lubricated.

The mill was fitted throughout with self-acting needle lubricators, all of which were in good working order. In addition to this, all the gearing was greased twice every twelve hours, and all the main bearings oiled by hand, so that the mill as a whole was exceptionally well lubricated. Indications taken of the entire plant, with engine and intermediate shafting, while making 9.65 sacks of flour per hour, with the oiling thus carefully attended to, showed 90 H.P.

A special oiling of every journal by means of ordinary oil-cans followed, and another set of indications showed that only 83.6 H.P. was being absorbed, which was a saving of 7 per cent. This saving, I repeat, was effected in a mill where all the working journals, etc., were already exceptionally well lubricated.

Indications of machines wholly dependent for their oiling on the needle lubricators were taken when the machines had been but a short time running, after standing for three days. These were compared with indications of the same machines after being, or rather *while* being, thoroughly lubricated by hand; the better oiling showed a saving of 21 per cent. of the horse power required to drive them.

Another set of indications taken of machines not fitted with automatic lubricators, half an hour after oiling by hand, showed that 10 per cent. more power was required than when the indications were taken *during* the process of oiling.

Conclusion.

I think I cannot better conclude this paper than by giving my earnest advice to every miller to take care that his roller plant is not taking too much power.

Throughout the series of trials, the one broad fact was everywhere apparent, that the amount of power that was being absorbed was a very good indication of the work that was being done ; indeed, if the power required to drive the empty machinery is deducted, it is a really reliable basis upon which to judge the system of manufacture. All other things being equal, the miller who turns out his flour with the least power is doing the *best* work, and I will go further and say that, all other things being equal, the miller whose plant takes the greatest power is doing the *worst* work. After the machinery is driven, the whole power absorbed is used in the separation of the inside of the berry from the outside, and the system that takes least power is that which separates it in the gentlest and tenderest manner.

The inside of any properly prepared wheat berry is easily reduced to sizes smaller than that of the skin which covers it, and with an ordinary medium mixture of wheat reasonably well cleaned, the power required to reduce the inside to flour is very small indeed. It is the skin, the strawy, woody covering, that is hard to grind ; and when once reduced, it can never afterwards be entirely rejected ; and the miller wastes power and injures his quality by re-rolling his granular flour in order to try and get it smaller than these branny particles that he had cut up and mixed with it. Let him remember that " prevention is better than cure," and that the using of excessive power not only increases the cost of production, but injures also the quality of the flour he manufactures.

APPENDIX I.

REVOLUTIONS OF CYLINDERS AT WHICH GRAVITY AND CENTRIFUGAL FORCE ARE EQUAL.

The Centrifugal force, C, acting on a particle moving in a circular path, is $= \frac{W\ v^2}{g\ R}$

Where W = the weight of the particle
v = its velocity in feet per second
g = acceleration of gravity = 32.2 ft. per sec. per sec.
R = radius in feet of the circular path.

If the downward pull of gravity, W, is to equal the centrifugal force C, then

$$W = \frac{W\ v^2}{g\ R} \text{ or } v^2 = g\ R$$

$$\text{or since } v = \frac{2\pi R N}{60}$$

where N = the number of revolutions per min.

$$N = 54.19\ \frac{1}{\sqrt{R}}$$

APPENDIX II.

GENERAL THEORY OF SEPARATION BY AIR RESISTANCE.

Any body of whatever size and shape, moving through air, is subjected to a force due both to surface friction of the air on the body and to internal friction of the air due to eddy motion set up in its wake.

The value of this force, except perhaps for dust, is given with sufficient exactness by the expression :—

$$F = K A V^2$$

where

V = velocity.

A = cross sectional area.

K = a constant depending on the shape of the body and its attitude to the line of motion.

The force on a perfectly symmetrical body moving along its axis of symmetry passes through the centre of gravity of the body and lies along its line of motion. For all other bodies the position and direction of the force, as well as its magnitude, depend on the shape of the body and its attitude to the line of motion.

When two bodies are moving in close proximity through air, a complex type of flow is set up round them which considerably modifies the forces on the individual bodies. For example, it has been found experimentally that when two circular discs are moving normally through air one behind the other, the force on the rear disc is completely reversed if the distance between the discs is less than $2\frac{1}{2}$ diameters, and it is considerably reduced for a much wider spacing. This is due to the formation of a region of low pressure turbulent flow between the discs. A similar distribution of pressure occurs when two bodies are moving side by side, a region of low pressure then being developed between them tending to make the bodies converge.

It will be seen from these considerations that the conditions for separation are somewhat complex. It is not sufficient that two bodies have different resistances but their orientation to the line of motion, and their proximity and position with regard to each other must be such that any forces set up, causing them to converge, are insufficient to overcome the difference in resistance.

Particles differ from one another in several ways, *e.g.*, size, shape, specific gravity, etc. In the absence of any restraining force all particles fall under the action of gravity with the same acceleration, and, at any given moment after release will have acquired the same velocity and have travelled the same distance. Particles falling in air encounter a restraining force due to the resistance of the air which is dependent on their velocity relative to the air. This force increases as the velocity increases until a speed is reached at which it is just equal to the weight of the particle, which then falls at a uni-

form speed. This speed, known as "the terminal velocity in air" is peculiar to each particle and can be found by substituting the weight of the particle for F in the equation above. It can further be shown that particles have different terminal velocities if they differ either in size, shape or specific gravity.

The difference in the terminal velocity of particles serves as a basis for their separation in two ways—

(1.) The particles to be separated are given a uniform horizontal motion in addition to the vertical motion due to gravity. The light particles travel further horizontally than the heavy ones before reaching a given distance below the starting point and hence a separation can be effected. The horizontal motion is usually obtained by dropping the particles into a horizontal air current, the velocity of which they acquire after a short acceleration period.

(2.) The particles to be separated are allowed to fall into an air current inclined upwards from the horizontal. The velocity of the air current is such that its vertical component lies between the terminal velocities of the light and heavy particles. The light particles are carried upwards by the air stream and the heavy particles fall downwards against it. This arrangement is obviously most effective when the air current is vertically upwards.

APPENDIX III.

THE LABORATORY ASPIRATOR.

The Laboratory Aspirator, diagrammatically illustrated in Fig. 42, consists essentially of a vertical wooden channel A, about 4 ins. square, leading at the top into a much larger channel B. In the narrow channel is a removable tray C, fitted with a wire gauze bottom, in which the sample to be tested is placed. Removable expansion boxes D are fitted where the narrow channel leads into the broad one; the lifted material is collected in these boxes which can readily be removed for examination and weighing.

The air is supplied to the aspirating channel from a fan E through louvres F so arranged as to give a uniform current up the channel. The air current is regulated by an iris diaphragm H, and the strength of the current can be read off directly from an inclined manometer K, fitted to a Peto tube in the aspirating channel. The manometer is graduated so that the air velocity can be read off in feet per second. A window L is provided in the aspirating channel so that a clear view can be obtained of the effect of the aspiration on the sample.

The sample to be tested is placed in the tray and the air velocity is gradually increased by manipulating the diaphragm on the fan until it is seen by inspection that the heavy berries are just not being lifted. The velocity is kept constant for a short time; the air is then shut off and the original sample and the liftings examined and weighed.

A test on this aspirator gives results comparable to a good working machine. The whole test, including the weighings, can be carried out in two or three minutes. In that time it is possible to determine what separation can be made by aspiration, and, with considerable accuracy, what air velocity is required and what percentage of impurities can be lifted.

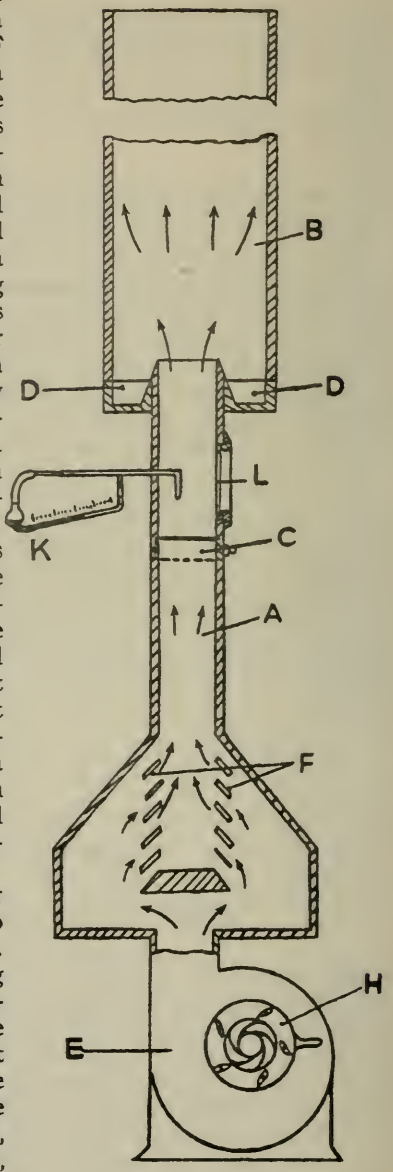


Fig. 42.
DIAGRAM OF LABORATORY ASPIRATOR.

APPENDIX IV.

CALCULATION OF THE EFFICIENCY OF AN ASPIRATOR.

Let n be the efficiency.

W = the impurities in the feed.
A = amount removed by the first aspiration.
B = ,, ,, ,, second ,,
C = ,, ,, ,, third ,,
etc.

Then $A = Wn$

and $B = (W - Wn)n$

Hence $$\frac{A}{B} = \frac{Wn}{(W - Wn)n} = \frac{1}{1 - n}$$

or $$1 - n = \frac{B}{A}$$

$$\therefore n = 1 - \frac{B}{A} = \frac{A - B}{A} \qquad \text{(I.)}$$

Also $$B = (W - Wn)n$$

and $$C = \left\{ W - Wn - (W - Wn)n \right\} n$$

Hence $$\frac{B}{C} = \frac{(W - Wn)n}{(W - Wn)n - (W - Wn)n^2}$$

$$= \frac{1}{1 - n}$$

or $$1 - n = \frac{C}{B}$$

$$\therefore \quad n = 1 - \frac{C}{B}$$

$$= \frac{B - C}{B} \qquad \text{(II.)}$$

APPENDIX V.

THEORY OF THE CYCLONE.

By G. WATTS, B.Sc.

A number of experiments have been carried out in our laboratories to determine the nature of the flow in a cyclone. The method employed was similar to that described in Chapter III. in the experiments on the flow in the separating channel of an aspirator. Small celluloid models were used and water was employed as the test fluid. Although corresponding speeds* could not be obtained, the results secured were sufficient to establish a theory of the action of the cyclone which has since been confirmed by measurements on full scale cyclones working on air.

Briefly the action is as follows: The dust laden air is led tangentially into the conical chamber and is guided round by the sides in a forced vortex. The rotary motion of the air thus established sets up at the centre of the cyclone a free spiral vortex extending right through the cyclone from the thimble to the dust outlet, and fed with air from the forced vortex mainly at the bottom. The diameter of the vortex is fixed by the diameter of the thimble.

Fig. 43.

MODEL CYCLONE DUST COLLECTOR.

* The speeds in water and air at which the same type of flow occurs

Fig. 43 is a photograph of one of the small cyclones being tested with water. The central vortex is shown by the dark band through the centre of the cyclone, which was obtained by introducing colouring matter into the bottom. The sharpness of the division surface between the forced and free vortices is very clearly shown. The steep cone of water leaving the top of the thimble indicates the enormous rotational energy of the free vortex.

The centrifugal force in the forced vortex is insufficient to separate any but the heaviest dust. The fine particles are carried down until the air enters the free vortex. Here they immediately come under the influence of a vastly greater centrifugal force and are thrown back into the forced vortex where they eventually settle on the sides of the cone and are ejected through the outlet at the bottom.

Any dust particle will be separated from an air current in a cyclone if the velocity relative to the air, impressed on it by the centrifugal force, is greater than the velocity of the air entering the free vortex. The centrifugal force at any point in a free vortex is proportional to the pressure gradient at that point*; therefore, for a given pressure drop from the outside to the centre of the vortex, the centrifugal force is inversely proportional to the diameter of the vortex. We have seen that the diameter of the vortex in a cyclone is fixed by the diameter of the thimble, therefore for geometrically similar cyclones the centrifugal force at the boundary of the vortex is inversely proportional to the scale.

Dust particles of the fineness of those separated in a cyclone most probably obey Stokes's law that the resistance is directly proportional to the velocity, and therefore their impressed velocity relative to the air is directly proportional to the centrifugal force. At the same time, the quantity of air passing through a cyclone for a given pressure drop is approximately proportional to the square of the scale†, and consequently the velocity of the air entering the vortex is practically independent of the size of the cyclone.

The fineness of the dust particles that can, in consequence, be separated in a cyclone increases as the diameter is decreased. In other words the efficiency of a cyclone when working on dust containing particles of different sizes increases with the reduction in the size of the cyclone.

* Gibson "Hydraulics and its Applications," Third Edition. Art. 47.
† From numerous actual measurements.

APPENDIX VI.

REMOVAL OF DUST BY A CIRCUIT ASPIRATOR.

By G. WATTS, B.Sc.

Let x = the dust originally in the wheat
y = the fraction of the dust left in the air after passing through the dust collector.
z = the fraction of the dust in the return air left after passing through the wheat.

That is, after the first aspiration, the dust taken out by the dust separator

$$= x(1-y).$$

And the dust returned to the wheat

$$= xy(1-z).$$

The value of z can only be estimated, but if the wheat berries are fairly well separated in the air channel it cannot well be lower than 0.8.

Now it can easily be shown that the dust in the air passing from the wheat to the dust separator, after prolonged working, is given by the sum of the infinite series

$$x + xyz + xy^2z^2 + xy^3z^3 + \text{etc.}$$

$$= \frac{x}{1-yz}$$

Therefore, the percentage of dust removed from the grain in its passage through the machine

$$= \frac{x}{1-yz} \times 1-y \times \frac{100}{x}$$

$$= \frac{100(1-y)}{1-yz} \%$$

Substituting 0.8 for z and assuming various values for the efficiency $(1-y)$ of the dust collector the following table can be compiled.

Efficiency of Dust Separator * %	Percentage of Dust separated from the wheat.
10	35
30	68
50	83
70	92
90	98

* In circuit machines actually in use this figure varies from 20% to 30% for simple settling chambers to 80% to 90 % for centrifuge type extractors.

APPENDIX VII.

REMOVAL OF SURFACE MOISTURE BY COLD ASPIRATION.

The following experiment was made with No. 3 Manitoba wheat having a natural moisture content of 13.3 %. The wheat was washed and whizzed in the usual way and it was then found to contain 17.7 % moisture. The whizzed wheat was immediately subjected to a strong aspiration by cold air. Air at atmospheric temperature was blown through a thin stream of wheat for two minutes at the end of which time the moisture content was found to be 15.65 %. That is to say, of the moisture left on the surface of the wheat by the whizzer, about 2 % was blown away by aspiration.

APPENDIX VIII.

TESTS OF STEAM CONSUMPTION OF THREE TYPES OF DRYERS.

Type.	Initial Moisture Content Per cent.	Final Moisture Content Per cent.	Moisture Removed; initial less final.	*Weight of Moisture evaporated per 100 lbs. grain treated Lbs.	Steam Condensed per lb. Water evaporated Lbs.
Hot Air Open Circuit...	18.5	16.69	1.81	2.17	2.75
Hot Air Part Closed Circuit ...	21.35	19.6	1.75	2.18	2.17
Surface Contact (Radiator)	19.9	17.0	2.9	3.49	1.65

* Moisture contents are always measured as a percentage of the weight of the wet grain; consequently the weight of water actually evaporated in any drying operation is greater per 100 lbs. of grain than the difference between the initial and final moisture contents.

APPENDIX IX.

METHOD AND ACCURACY OF ASH TEST.

A large number of samples of one flour were treated, batches of five being inserted into the oven together at each heating. The average ash content was found to be .32 % ; the highest individual result being .35 % and the lowest .28 %. The mean value of any five samples treated together was found to vary between .34 % and .30 %. In order to eliminate irregularities in the heating on any given occasion five samples were taken from five batches heated at different times. In that case the maximum value was found to be .33 % and the minimum .31 % thus showing a maximum error of .01 %.

As we were anxious, for the purpose of these tests, to arrive at the most reliable result, we have adopted this method as the standard, that is to say, our figures are always the mean of five samples taken from five different heatings.

This error in the weight of the ash is expressed as a percentage of the weight of the original flour sample. This is the most usual way of expressing it, but for some purposes it is important to express the error as a percentage of the weight of the ash itself. In the case given in Table I., by our standard method the error so expressed would be $\pm$ 3.1 %. This means that when we determine the amount of bran powder present in a given sample of flour, the maximum error expressed as a percentage of the weight of the flour is .01 %, or expressed as a percentage of the weight of the bran powder present, is 3.1 %.

Table II. shows how these maximum errors are changed when we come to deal with bran ; owing to the ash being a much larger percentage of the whole the figures are considerably altered. Working on our standard method we see that expressed as a percentage of the weight of the stock the maximum error is $\pm$ .03 %. Taken as a percentage of the weight of the ash the error is .5 %.

The maximum error is, therefore, on a sliding scale ; when measured as a percentage of the stock the error increases from .01 % in the case of flour to .03 % in the case of bran ; when measured as a percentage of the ash it decreases from 3 % in the case of flour to .5 % in the case of bran.

TABLE I.

VARIATIONS AND ERRORS IN ASH TESTING.

SAMPLE OF "C" FLOUR.

Mean value of all tests=0.32 %.

	Max. Value % of Stock.	Min. Value % of Stock.	Maximum error	
			% of Weight of Stock.	% of Weight of Ash.
Individual Samples ...	0.35	0.28	+.03 −.04	+ 9.4 −12.5
Mean of five samples at one heating	.34	.30	±.02	± 6.2
Mean of five samples in five different heat'gs	.33	.31	±.01	± 3.1

TABLE II.

VARIATIONS AND ERRORS IN ASH TESTING.

SAMPLE OF BRAN.

Mean value of all tests=5.81 %.

	Max. Value % of Stock.	Min. Value % of Stock.	Maximum error.	
			% of Weight of Stock.	% of Weight of Ash.
Mean of five samples in five different heat'gs	5.84	5.78	±.03	±0.5

APPENDIX X.

CELLULOSE MATERIAL.

The division of the products of the wheat berry into flour and bran is not, strictly speaking, correct. The endosperm, all of which is considered as flour in this table, contains a certain amount of cellulose material which forms the cell walls. If the ash content of the cellulose differs from that of the flour, and if the percentage of cellulose varies in the endosperm portion of the stocks tested, the true ash content of the endosperm will not be as given in the table; consequently there will be an error in the estimate of the amount of bran present. The ash content of endosperm cellulose is not known, but there is reason to believe that it is not much higher than that of flour. Kent-Jones has shown ("Modern Cereal Chemistry," 2nd Edition, Table LV., page 209) that "H" flour, which is rich in cellulose material (0.31 %) and has also a high bran colour figure (12.0), has an ash content of only .62 %. If the ash content of cellulose were much higher than that of the flour, this figure would be considerably higher. Moreover, the ash content of "beeswing," the outer cellulose skin of the berry, which must be high owing to contamination with dirt, has been found to be only 1.85 %. If the ash content of the cell walls is taken as 1 % and the increase in the amount present in the endosperm portion of any stock 2 %—actually three times the cellulose content of the lowest grade flour given in Kent-Jones's table above referred to—the increase in percentage of ash in the endosperm portion would be rather less than .02 %, a figure of the same order as the error in the ash test itself. The error which is introduced by including the cellulose material as flour, cannot, therefore, have any serious effect on the results obtained.

APPENDIX XI.

ERROR IN ESTIMATION OF BRAN POWDER.

The degree of error in the estimation of bran powder depends on two things :—

1. The accuracy of sieving.
2. The accuracy of the ash test.

The possible error of the sieving test has not been found very accurately ; the maximum error in the weight of the throughs is not greater than 10 % when the amount of the throughs are small (*i.e.*, 1 % of the whole sample), nor greater than 1 % when the throughs are large (*i.e.*, 20 % of the sample).

The limits of error of the ash test have already been shown to vary from .01 % to .03 % for branny stocks.*

The possible error in the bran powder test can only be obtained, therefore, as a combination of two other errors, both of which are on a varying scale of magnitude, according to the purity of the stock.

The simplest way of indicating approximately how big the maximum error may be is to consider, for example, the figures given in Table I., Chapter VIII., which shows a production of .26 % of bran powder. Let us assume that the maximum error has been made in the bran powder test, both on the feed and on the delivery, and that the true values are in the feed greater and in the delivery less than shown.

As regards feed, the throughs instead of being 1.8 grams might in fact weigh 1.98 grams, and the ash content instead of being .65 might be .67. In that case, the actual bran powder would work out at .13 grams.

Coming to the delivery, the yield might be 1 % less than shown, or 13.05 grams, and the ash content .46 instead of .47, making the actual bran powder .34 grams.

Assuming in this way that the maximum error has been made, both in the feed and in the delivery, in such a way that when the two errors are added together the bran powder produced would amount to .21 % instead of .26 %, this may be regarded as the maximum possible error under these conditions.

* Appendix IX.

APPENDIX XII.

ERRORS IN PURIFIER TESTS DUE TO CELLULOSE.

If we assume that the stock fed to a purifier actually consists of :—

92 % endosperm with ash content	.32 %
6 % bran with ash content	5.8 %
2 % cellulose with ash content	1.8 %

the ash content of the mixture will be :

$$92\times\frac{.32}{100}+6\times\frac{5.8}{100}+2\times\frac{1.8}{100}=.678\ \%$$

From Table III., Chapter VII., we see that this ash content is equivalent to a bran content of 6.54 % as against the 6 % bran and 2 % cellulose actually contained in the mixture.

If we further assume that the bran and cellulose, together with 10 % of endosperm, are separated out in the tails from the machine, a sample of these tails will contain 10 parts endosperm, 6 parts bran, and 2 parts cellulose, and the ash content as calculated will be

$$\frac{10\times\frac{.32}{100}+6\times\frac{5.8}{100}+2\times\frac{1.8}{100}}{18}\times 100$$

$$=2.31\ \%$$

and the bran content taken from the Table would be 36.36 % instead of 33.33 % bran and 11.1 % cellulose.

A simple calculation will show that the ratio of the bran figures, as taken from the Table, to the total offal (bran and cellulose) is the same in the feed as in the tails. It is clear, therefore, that if the bran figure is considered as a relative rather than an absolute value it does give a very fair comparison of the amount of offal in stocks of very diverse character.